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Monthly Bulletin of the International Railway Congress Association

(English Edition)

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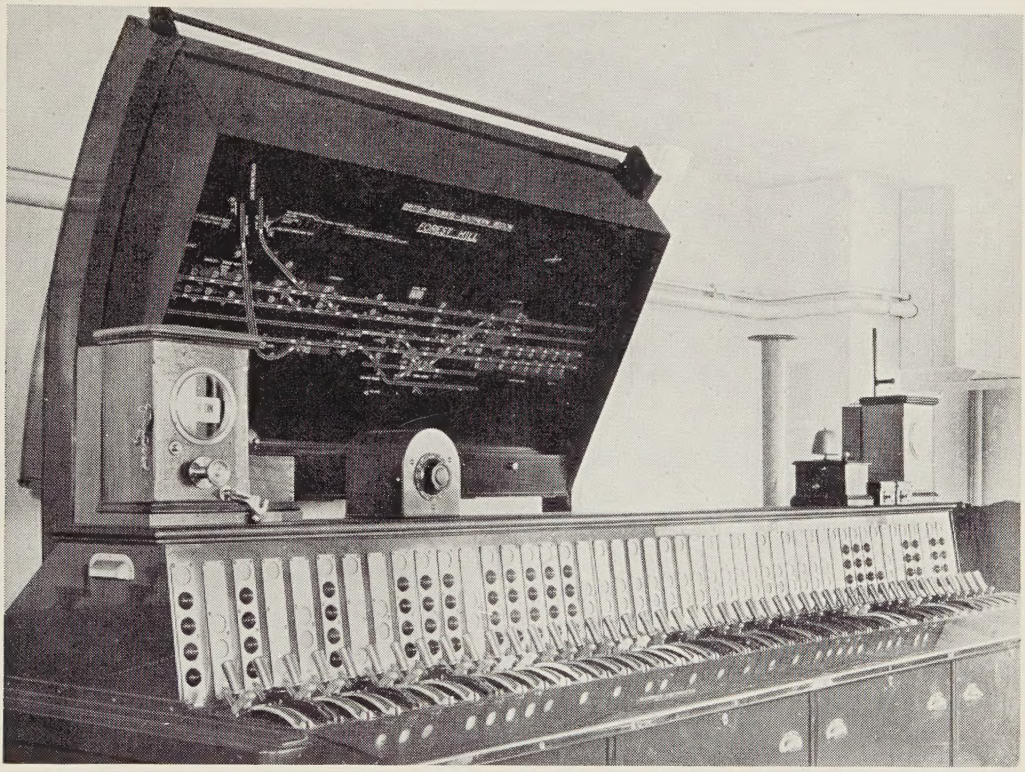

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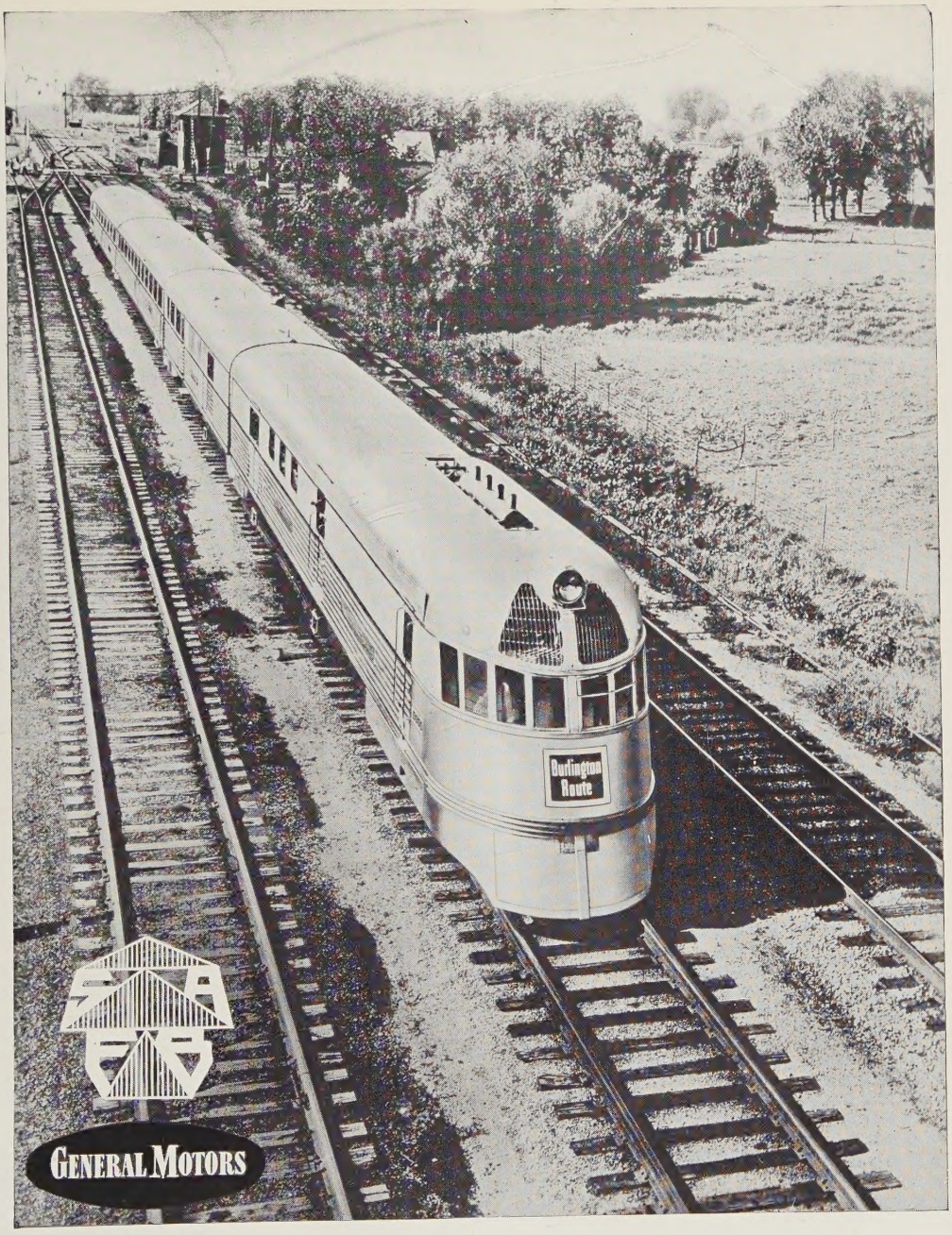

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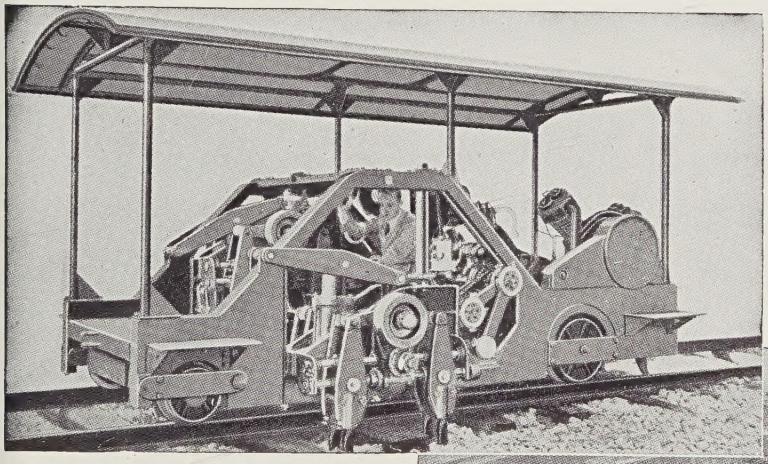

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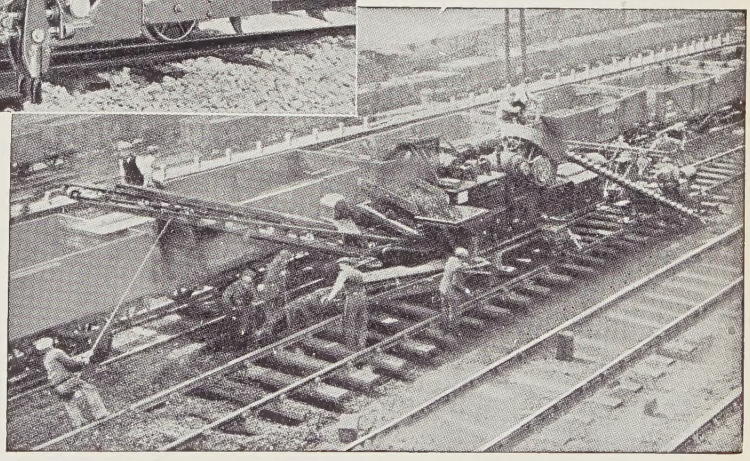

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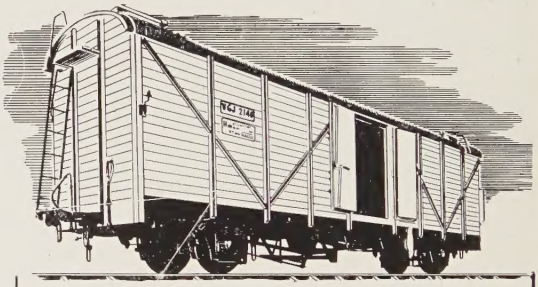

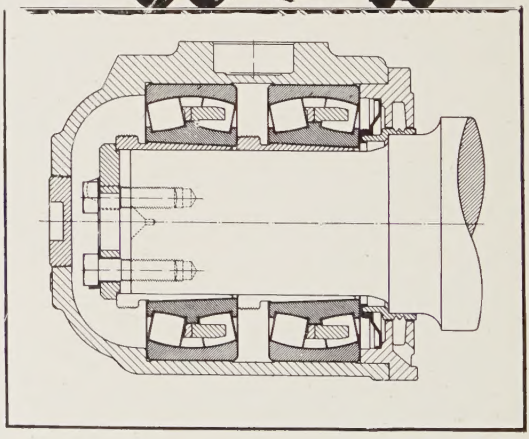

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Vol. XXVIII. — No. 11. November 1951.

BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

[625 .251]

Braking of trains.

CALCULATION OF STOPPING DISTANCES,

by J. A. POULET, Engineer, A. I. Br.

(Prize work of the Special Fund constituted by the Northern Railway Company.)

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INTRODUCTION

The determination of the stopping distances of trains has an important place amongst the questions on the working of railways, which is as much justified theoretically as practically.

Actually, brake calculations are based on the knowledge of the laws of variation of coefficient of friction between the brake shoe and the wheel, which is the reason for the large number of investigations carried out with a view to determining, as accurately as possible, these laws of variation in the function of speed, pressure, etc.

Having acquired this knowledge, it is necessary to examine the method of the working of brakes in order to determine their characteristics and especially the law of increasing force applied to the shoes in relation to the function of time.

The comparison of these two elements,

together with the interpretation of the results of brake trials carried out on isolated vehicles or on trains enables the stopping distances to be determined for trains running at varying speeds on lines having different gradients.

These stopping distances, determined for the various categories of trains (passenger, express freight and goods trains) enable brake regulations to be laid down, to which trains working on a line must conform when signals are placed at a given distance or high speeds are in question and maximum braking is carried out. These stopping distances serve as the basis for determining the distances at which signals are placed.

It should be noted, in certain special cases, owing to reduced visibility or the absence of any signalling arrangement, that it is the speed of the train which is the last unknown item of the problem, it being taken that the braking is at the maximum and the stopping distance reduced to the very minimum (200-300 m) (218 to 328 yards).

It could be deduced from the preceding that the determination of the stopping distances and the fixing of brake regulations does not present particular difficulties because the laws of the variation of the coefficient of friction have been the subject of much research, for more than three-quarters of a century and also the method of the working of brakes is equally well known owing to rivalry and competition which has been shown both in scientific research and inventions.

It can assuredly be affirmed that if the calculated stopping distances were an easy problem, brake regulations would not differ so widely between one railway system and another. This divergence, however, does exist and efforts recently made by the International Union of Railways (U. I. C.) to standardise brake regulations have not been crowned with success. Some figures will enable the situation to be appreciated.

For a parcels train working at 100 km/h (62 m.p.h.) on a line where the signals are spaced at 1 000 m (1 093 yards) the percentages of weight-brake required are the following :

Sweden	49 %
France	52 %
Belgium	59 %
Germany	64 %
Italy	65 %

On many railway systems the brake calculations are made in accordance with formulae of more than 40 years ago or in accordance with results of trials carried out hardly more recently.

Whilst the study of the laws of the variation of the coefficient of friction has been pursued, almost without interruption, since 1858, it can be stated that the regulations of many Administrations have been retained in the form they were in about 1910.

However, the application of compressed air brake to goods trains which was carried out on most of the Continental Railway systems from 1925 to 1935 has led to brake trials which have, fortunately, increased the information available, although generally, scientific publications have not had a sufficient circulation.

The lack of uniformity of regulations regarding the application and release of brakes between the time of experimental discoveries and that of their introduction

into the regulations would appear to be due in the first place to the complexity of the calculations through the superposition of the variations of the coefficient of friction applied to a force at the brake shoes which itself varies with time. In addition, many Administrations are excessively cautious, showing little haste to adopt improvements, even those which are most useful and have been most carefully studied.

Undeniable proof of the complexity of the calculations is shown by the two articles, which appeared in 1948 in the *Bulletin of the International Railway Congress Association*, and were written by Mr. Hennig, who established, with mathematical precision, the stopping distance of a goods train after very long calculations developed over about 20 pages.

It should also be noted that Mr. Hennig simplified considerably the calculations by admitting that the coefficient of friction varies geometrically with the speed (Doyen's formula), although more recent theories assign a law of hyperbolical variation to the coefficient of friction.

To avoid the difficulty of too long and too laborious calculations, our researches have been towards a method of approach applicable to all types of brakes (passenger or goods). This method permits the resolving of various problems raised in the operation, by the use of a relatively simple formula. This formula can even be transformed in a nomogram and all problems cited can be resolved by a simple graphical process.

An idea of the advantage of the graphical process and the economy in calculations which is procured can be appreciated by recalling the equations used for linking the stopping distance to the maximum speed, and to the percentage of weight-brake which can cover a speed range of 20 to 140 km/h (12 to 87 m.p.h.) and a range of the distances of 200 to 1 600 m (218 to 1 750 yards).

I. Determination of the value of coefficient of friction.

Problems regarding braking of rail vehicles have been studied since the beginning of railways. The data obtained by the end of the last century were the results of patient efforts of many experimenters, amongst whom the names of Poirée, Bochet, Douglas Galton and Wichert are particularly well-known. From this data, other experimenters have proposed various formulae with the object of translating into mathematical terms the variations of the coefficient of friction under the influence of the three essential factors which were brought out by Douglas Galton :

1) speed;
2) pressure;
3) duration.

Between the work of Douglas Galton (1878) and that of Wichert (1894), numerous formulae were introduced by Doyen, Seguela, Soulerin, Fliegner, Franke and Petrov. These formulae decreased the coefficient of friction when the speed increased, but according to very different laws : linearly for Doyen, Seguela and Soulerin, hyperbolically for Fliegner and Petrov, and exponentially for Franke.

Tests carried out by Wichert confirmed that the hyperbolical curve represented the variation of the coefficient of friction

in regard to speed, but these tests also showed the existence of considerable differences due to the condition of the surfaces in contact, wetness reducing friction up to 45 % of the value observed when the surfaces in contact are perfectly dry.

After the First World War, new tests were undertaken by METZKOV (1926), who studied the influence of pressure and the respective hardness of the surfaces in contact. Some tests were also undertaken in America in 1930 to measure the influence of pressure on the coefficient of friction.

Messrs. PARODI and TETREL, in their work entitled *Electric Traction*, which appeared in 1935, gave an excellent summary of the information which had been acquired up to that time on the subject of the laws of friction.

Their conclusion was that BOCHET's experiments, although the first (1858), and the law which translates them :

$$\frac{0.33}{1 + 0.0233\ V}$$ (V expressed in km per hour)

were confirmed by later research which had been carried out for more than three-quarters of a century.

New tests, however, were carried out up to the beginning of the Second World War by the German State Railways (1935), the University of Illinois (1938) and the Central Scientific Research Institution of Russia (1938), in order to bring out the influence of speed, pressure, duration, temperature and hardness of metals in contact.

To the names of those previously mentioned should be added RECKL, SCHRADER, BABICKHOV, EGORTCHENKO, HENNIG, CHRISTEN, PEDELUCQ and KARVATZKI who, from all quarters of the globe, have added their contribution to the study of a question of the greatest interest, as it is on its solution that a large number of important matters in the working of railways rests, especially the increase of speed, the determination of the distance at which signals should be spaced, the regulations regarding the composition of trains, etc.

According to our information, credit must be given to an English engineer, Mr. Jury KOFFMAN, for the most up-to-date information on the subject of adhesion and friction given in his paper read before the Institution of Locomotive Engineers on the 20th October, 1948. His report, well supported by documentary evidence, set out the essential points of the work of many different investigators, whom we have mentioned previously, and he has drawn the most useful conclusions for those who must adapt for practical use, the results of the tests.

The aim in this paper is essentially practical, only brief particulars will be given of the various laws proposed to express the variation of the coefficient of friction with the factors on which the influence is predominant to find the speed and the pressure.

Certain of these formulae give results very near to one another and a choice has been made amongst those which show a stage in the already long history in the study of the laws of friction.

The most outstanding laws of variation are shown in Appendix 1.

As has already been pointed out, the investigators endeavoured to show the influence of speed, although DOUGLAS

Galton has also shown the influence of pressure.

Regarding the influence of speed, the comparison of the proposed formulae show that the law of Doyen :

$$f = 0.270 - 0.0072\ v \quad (v \text{ in m/sec.})$$

is satisfactory for slow speeds, but must be replaced by another law for speeds higher than 80 km/h (50 m.p.h.).

The hyperbolical formulae (Bochet, Fliegner-De Blieck and Parodi-Tetrel), although better, also show too great a drop of the coefficient of friction at high speeds. Regarding Wichert's formulae, these obiously give too poor results at slow speeds. If it is desired to compromise between these various propositions the discontinuous variation must be admitted :

$$f = \frac{14\ 520}{V + 44}$$

(Fliegner-De Blieck) of 0 to 65 km/h (0 to 40 m.p.h.),

and $$f = 90\ \frac{V}{V - 20}$$

for high speeds,

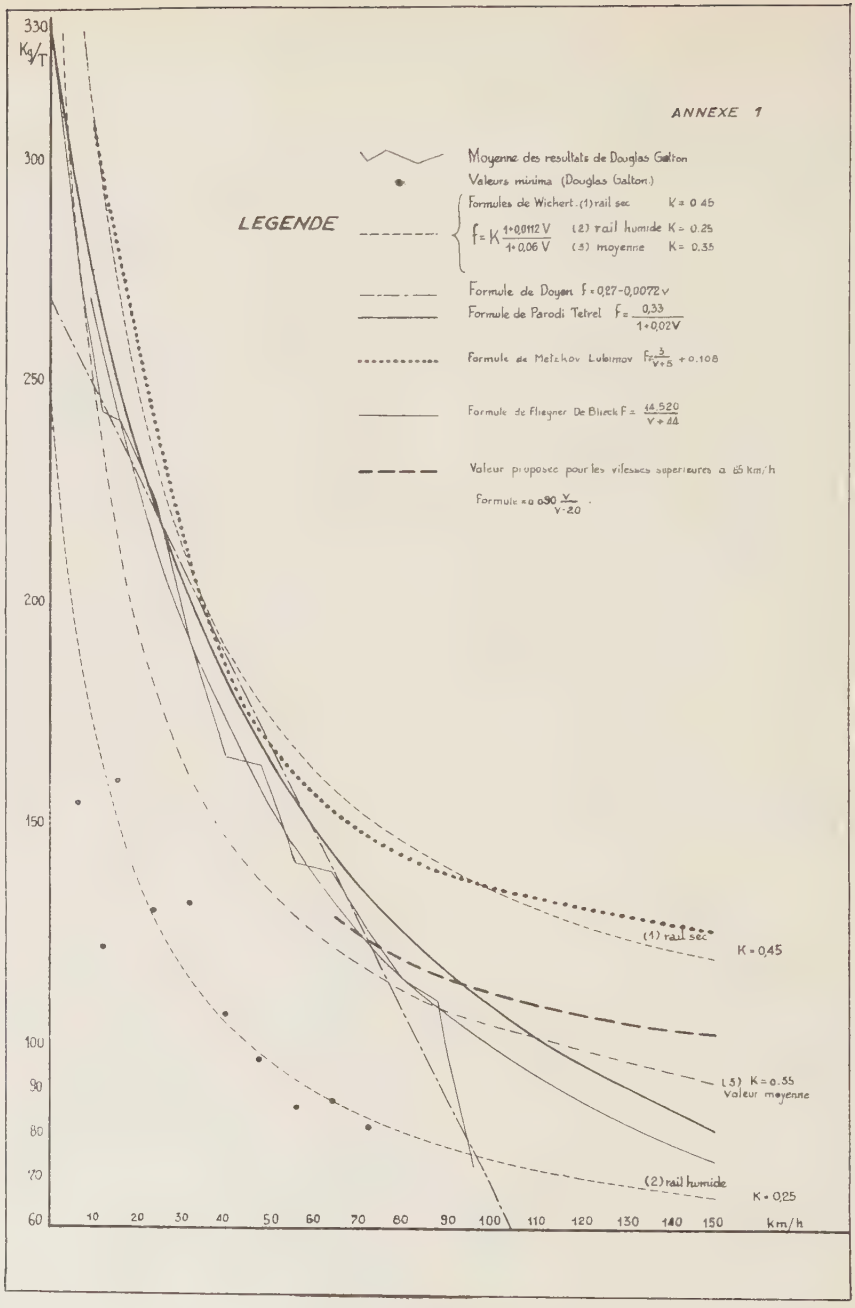
unless it is admitted that the coefficient of friction varies with the speed according to a law represented by a curve of the third degree. As will be seen later, this last solution will readily incorporate the requirements regarding the intervention of pressure, but makes the integral calculations for determining the braking time and stopping distances more difficult.

The formulae adopted to express the variation of the coefficient of friction with the speed are only valid for a *determined pressure*. Indeed, Douglas Galton's experiments show that the coefficient of friction *diminishes* with increasing pressure.

Until the beginning of the 20th Century, the influence of pressure did not play a very important role : most vehicles had, except locomotives, brake rigging having a force of approximately 2 000 kg (4 409 lbs.) on each shoe, corresponding to a pressure of 7 kg/cm² (99 lbs. per squ. inch). At this time, only passenger coaches were fitted with compressed air brake, goods trains being hand braked. As for locomotives, the weight of which is much higher per axle than that of other vehicles, the force at the shoes had to be limited to two-thirds of the weight of the driving axles and half the weight of the bogie.

Douglas Galton's experiments included pressures of up to 10 kg/cm² (142 lbs. per sq. inch) and the decrease of the coefficient of friction when the pressure increased could be easily observed.

In consequence pressures used for braking trains varied between high and low limits for clear reasons. On the one hand, the fitting of compressed air brakes to goods trains necessitated the use of low pressures, owing to the danger of skidding of wheels of empty vehicles. Consequently, wagons with a low tare could not have the force per brake shoe greater than 1 000 kg (2 205 lbs.) that is to say, a pressure of approx. 3.5 kg/cm² (49 lbs. per sq. inch). On the other hand, passenger trains, the speed of which had considerably increased, had to be equipped with more and more powerful brake gear, attaining 4 000 kg (8 820 lbs.)per brake shoe (14 kg/cm² — 199 lbs. per sq. inch). Moreover, it was at this time that the need to double the brake shoes on very heavy vehicles (locomotives) or of


ANNEXE 1
LEGENDE
Moyenne des résultats de Douglas Galton
Valeurs minima (Douglas Galton)
Formules de Wichert. (1) rail sec K = 0.45
(2) rail humide K = 0.25
(3) moyenne K = 0.35
Formule de Doyen F = 0,87 - 0,0072 v
Formule de Parodi Tetrel F = 0,33 / 1+0,02V
Formule de Metzkov Lubimov
Formule de Fliegner De Blieck F = 14,520 / V+44
Valeur proposée pour les vitesses supérieures à 65 km/h
Formule = 0,90 V / V-20
Kg/T
330
300
250
200
150
100
90
80
70
60
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 km/h
(1) rail sec
K = 0,45
(3) K = 0.35
Valeur moyenne
(2) rail humide
K = 0,25

Appendix 1.

KEY.

Average of Douglas Galton's results.
Minimum values (Douglas Galton).
Wichert formulae (1) Dry rail.
(2) Wet rail.
(3) Average.

Explanation of French terms :

Doyen's formula.
Parodi Tretel's formula.
Metzkov Lubimov's formula.
Fliegner de Blieck's formula.
Proposed value for speeds above 65 km/h formula.

those equipped with a brake of which the power varied with the speed (auto-variable brake) was realised.

In order to define clearly the influence of pressure on the value of the coefficient of friction, some characteristics figures are given below :

A. *Trials of Metzkov.* Values of f (kg/t) for pressure of :

Speeds	Kg/cm²				
	2	4	6	8	12
120	—	170	142	135	120
100	182	171	150	140	130
80	188	170	160	150	147
60	220	181	178	172	168
40	258	222	218	190	180

B. *Trials carried out in U. S. S. R. :*

Speeds	Kg/cm²					
	2.5	6	8	9	10.5	14
80	—	103	—	80	—	—
60	130	110	95	87	80	75
40	160	125	110	101	94	86
20	210	170	145	137	126	120

Comparison of the results obtained by the two series of experiments showed considerable differences. Metzkov's tests had been carried out in a laboratory, whilst those of the U. S. S. R. which were confirmed by similar trials in Germany, had been carried out on the line. Whilst the former threw light on the physical and theoretical aspect of the problem, the latter took into consideration additional factors which can seriously modify the value of the actual force applied at the shoes, i. e. dust, humidity, play in the brake rigging, etc.

These tests must, above all, serve as a guide to establish a law of variation linking the coefficient of friction to speed and pressure, it being understood that when choosing a suitable value for this coefficient, the nature of the problem in question must be borne in mind and the best solution chosen in accordance with safety.

In other words, the « lower » values of the coefficient of friction must be chosen to determine the stopping distances of trains, whilst « higher » values are used to establish the pressure that can be exerted on a wheel without risk of skidding.

Mr. Jury Koffman in his paper already mentioned, estimated that the three variables of the problem are linked by the form :

$$f_{V_2 p_2} = f_{V_1 p_1} \sqrt[3]{\frac{V_1}{V_2}} \times \sqrt[3]{\frac{p_1}{p_2}}$$

The following can be chosen as normal limits of pressure and speed : V 160 km/h (100 m.p.h.) and p 16 kg/cm² (227 lbs. per sq. inch) on the one hand and V 20 km/h (12 m.p.h.) and p 2 kg/cm² (28 lbs. per sq. inch) on the other. It can be seen immediately that if X represents the value of the coefficient of friction for 160 km/h and 16 kg/cm², this coefficient will equal 4 X for 20 km/h and 2 kg/cm².

In order to take into consideration the

Speeds	Kg/cm²							
	2	4	6	8	10	12	14	16
20	220	175	152	139	128	121	115	110
40	175	139	121	111	103	96.5	91.5	87.5
60	152	121	105	96	87.5	84	79.5	76
80	139	111	96	87.5	81.5	77	72.5	69.5
100	128	103	87.5	81.5	75	70.5	67	64
120	121	96.5	84	77	70.5	67	63.5	60.5
140	115	91.5	79.5	72.5	67	63.5	60	57.5
160	110	87.5	76	69.5	64	60.5	57.5	55

least favourable results in the value of the coefficient of friction, the figure of 55 kg per ton for 160 km/h and 16 kg/cm² has been chosen. The other values are given in the table above.

These values have been shown graphically in Appendix 1A. The curves consist of a series of cubic parabola.

Other elements which influence the value of the coefficient of friction, i. e. hardness of the shoes, duration of application, temperature, etc., will not be gone into. Regarding the condition of the surfaces in contact, very low values have been chosen for the above table, which give sufficient safety to cover the most unfavourable conditions.

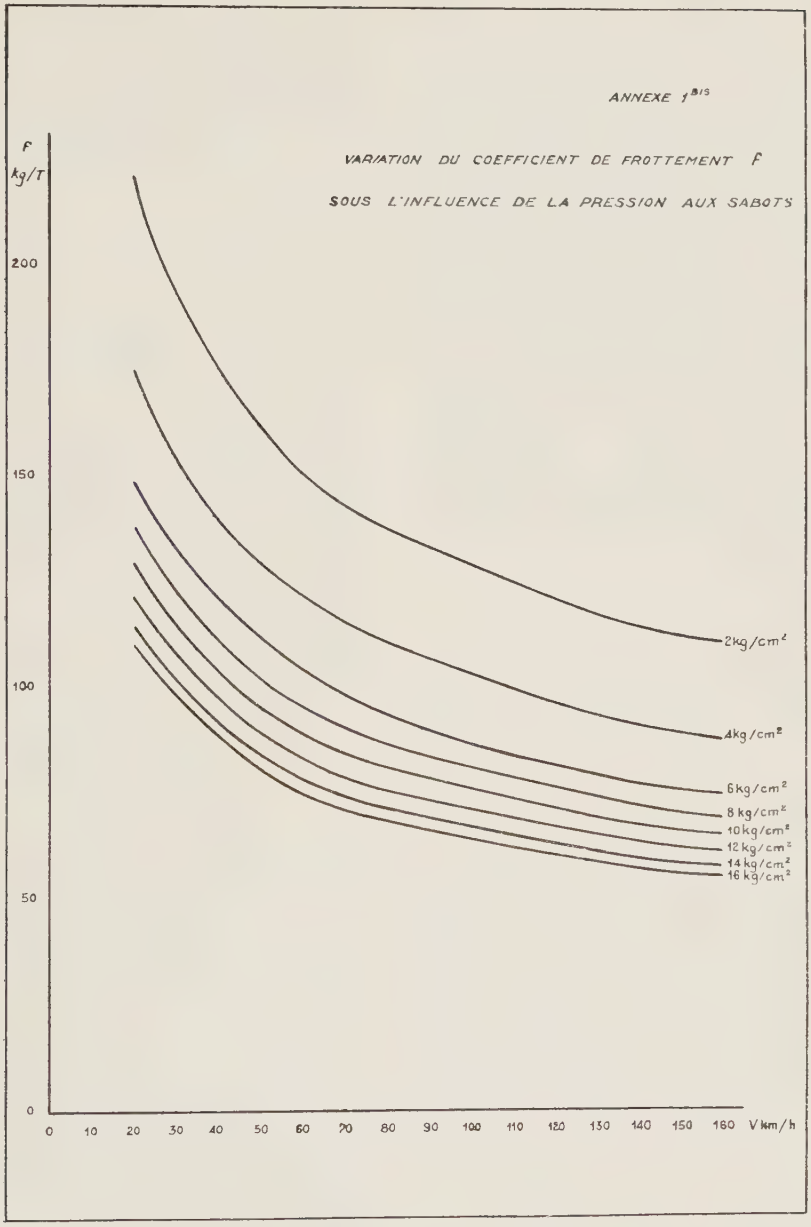
II. Determination of retarding force developed by the shoes during braking.

If a force Q is exerted on a shoe applied against a wheel during braking, the force opposing the rotation of the wheel under the action of the shoe has the value of :

$$F = fQ$$

The work carried out to determine the value of f, which varies essentially at different speeds and pressure at the shoes, is now reviewed. The force Q and, in consequence, the pressure at the shoes, can be applied on the wheels in a very short time (rapid acting brake) or gradually (braking of goods trains).

In the first case, Q being constant during the whole of the braking, the determination of the value of F may become confused with that of the coefficient of friction f. This latter, varying only as the speed (the pressure being constant), the speed curve plotted against time will enable the value of F to be expressed as a function of the time and from this the *mean value of the retarding force* can be obtained during the brake application. The integration is easy



APPENDIX 1A.

Explanation of French terms :

Variation of coefficient of friction F due to varying pressure at the shoes.

when the elements vary linearly with the speed. It becomes very complicated if the movement of the train is taken into consideration in the equations so that the coefficient of friction varies with the cube root of the speed whilst the running resistance is a constant term, a term V and term V^2, due to the resistance of air. This is why one is led to integrate between the limits of the speed at certain intervals a linear variation can be admitted for all the elements considered (friction and running resistance). The method of calculation followed from the fundamental theorem of the chance of kinetic energy applied to a train of mass M stopped in a distance L from an initial speed v_0 expressed in metres per second, is as follows :

$$-\frac{Mv_0^2}{2} = \int_o^L \Sigma F dL$$

Let :

P = the weight of train in kg;

Q = the sum of the force at the shoes;

α = the quotient $\frac{Q}{P}$ or the coefficient of braking;

$r = r_1 + r_2 . v$ the running resistance;

$f = f_1 - f_2 . v$ the coefficient of friction, what is assumed to vary with the speed between the limits v_1 v_2. To take into consideration the inertia of the revolving masses, the mass of the train is obtained by multiplying its weight by $\frac{1.088}{g}$. The original equation becomes :

$$\frac{1.088}{2g} v_0^2 = \frac{Q}{P} \int_o^L (f_1 - f_2 . v) dL + \int_o^L (r_1 + r_2 . v) dL$$

This is on the hypothesis that the line under consideration is level.

After differentiation and simplification, the following is obtained :

$$v dv = (C - Dv) dL,$$

where :

$$C = \frac{g(f_1 \alpha + r_1)}{1.088}$$

and :

$$D = \frac{g(f_2 \alpha - r_2)}{1.088}$$

If it is desired to determine the duration of the braking or its length, this latter equation will be written then integrated under one of the following forms :

$$dt = \frac{dv}{C - Dv} \quad \text{or} \quad dL = \frac{v dv}{C - Dv}$$

duration of braking :

$$t = \frac{1}{D} \text{ log. N.} \frac{\frac{C}{D} - v_2}{\frac{C}{D} - v_1}$$

the length equals :

$$L = \frac{1}{D} \left(v_2 - v_1 + \frac{C}{D} \text{ log. N.} \frac{\frac{C}{D} - v_2}{\frac{C}{D} - v_1} \right)$$

It is, of course, understood that the times t and the lengths L are the times and lengths obtained for the interval v_1 to v_2, the first speed being the initial speed of the train and the final speed being nil (stop).

If this method of calculation for the stopping distance of a train is used

with a known coefficient of braking $\alpha = \frac{Q}{P}$, in the energy equation the integrals of 0 to L can be replaced by expressions using the *average values* both for the coefficient of friction and for the running resistance. The equation becomes:

$$\frac{1.088}{2\,g}\, v^2 = (\alpha f_m + r_m)L$$

which is written as follows to express the speed in km/h :

$$L = \frac{4.24\ V^2}{\alpha f_m + r_m}$$

In this form the formula for stopping distance is well known and has been used with variations by the different authors of braking formulae.

It must now be explained how leaving this formula one is led to an equivalent expression in which the product αf_m is replaced by another, showing the *weight-brake* of vehicles. It should be noted that as soon as *average* values are used it is possible to dispense with the index symbol; therefore, f is written in lieu of f_m and r in lieu of r_m.

In order to understand better the reason why the term weight-brake has been chosen to indicate the braking power of a vehicle, the methods of calculation used for determining the stopping distance of goods trains braked *by hand* must be used.

For safety reasons, in order to determine the stopping distances of these trains, a specific force αf (expressed in kg/t) necessary to brake the wheels without skidding is not taken but the most unfavourable case that can occur, i. e. the sliding on the rails of the train, the wheels of which would be locked due to too large force applied on the hand brake.

In this hypothesis of sliding on rails, the coefficient of friction of steel on steel being less than that between iron and steel, was taken as 0.104 (104 kg/t), irrespective of the speed (actually, this would not exceed 45 km/h) (30 m.p.h.) and irrespective of the pressure existing between the tyre and the rail.

It is, of course, understood that the force by which it is necessary to multiply this coefficient of friction is no longer the force Q exerted on the shoes, but the force P′ on the braked and locked wheels, assuming that they are sliding on the rails. By analogy with the coefficient α expressing the relation between the force Q and the weight P′, $\lambda = \frac{P'}{P}$ which is called *proportional braking* is introduced in the formulae. The formula used was :

$$L = \frac{4.24\ V^2}{0.104\,\lambda + r}$$

When the compressed air brake was used on goods trains, in the first place methods of calculations used for passenger trains were used, that is to say, the brake power was measured by the force Q applied at the shoes. Also, the relative importance of this braking to the weight of the train was expressed by the *coefficient of braking* $\alpha = \frac{Q}{P}$.

The force Q obtained from the brake cylinder dimensions and the leverage of the brake rigging has been chosen in order to prevent the locking of the wheels. To

obtain this result, the following reasoning was used :

To avoid the locking of a wheel, it is necessary that $Qf \leqslant Pa$ (a = coefficient of adhesion) particularly at slow speeds. Experience showed that at slow speeds one generally had : a = from 0.20 to 0.25 and f = 0.30 to 0.35. It is for this reason that at the outset the coefficient value of $\alpha = \frac{Q}{P}$ was limited to 0.66 or 0.70. For a wagon braked solely on the tare weight, to limit the force at the shoes to 7/10 of the weight on rails was a general rule, whereas for passenger vehicles the force at the shoes was at least equal to 8/10 of the tare.

This difference is easily explained by the following :

a) Carriages run empty less frequently than wagons and their load is much more uniform.

b) The pressure at the shoes being greater for coaches than for wagons, the coefficient of friction is lesser and therefore the danger of locking is less, which permits the adoption of a higher coefficient α.

c) Speeds being higher for coaches, a higher value of α is indicated, both owing to the value of the coefficient of friction being lower and its being essential for it to be brought to a standstill in the same distance as that permitted for goods trains.

The above also explains the difference between the definitions of weight-brake permitted for passenger trains, as against goods. This duality has formed a serious obstacle to efforts made to standardise brake regulations between the various railway administrations.

This can be demonstrated more clearly by an example: a wagon having a tare of of 10 t — and of which the force at the shoes is 7 t — has, by definition, a weight-brake of 10 t — brake whilst that of a coach of 40 t — tare would have 40 tonnes-brake, and a force of 32 t at the shoes. The disadvantages of this double definition of the tonnes-brake are shown more clearly when it has been necessary to indicate the brake power of vehicles equipped with *mixed* type brakes (passenger and goods). The brake value for the passenger vehicles is estimated, for example, at 17 tonnes-brake whilst with the same force at the brake shoes that for goods corresponds to the value of 16 tonnes-brake.

When greater pressures are used, as in the case of brake shoes on locomotives, the weight-brake of the vehicle is taken equal to the force at the shoes or, at the very most, 110 % of this force. These differences are explained if the influence which the pressure exerts on the value of the coefficient is recalled.

As a matter of fact, wagons braked in accordance with the tare, only have a pressure of 5 kg/cm² (71 lbs. per sq. inch) whilst for the locomotive three times this value is reached. For the same speed the coefficient of friction will be reduced from 150 to 100 when one goes from 5 to 15 kg/cm² (71 to 213 lbs. per sq. inch).

By the foregoing, it can be seen that weight-brake, which at the outset (in the case of hand brake), was thought to be connected with the physical idea of *weight braked* or weight on rail, is no more than a figure translating brake power and which,

in consequence, can be greater, equal or less than the weight on the braked axles.

The idea of the weight-brake presented more scientifically in relation to the force at the shoes, has the advantage of being more familiar to the staff as the terminology used for hand brakes is employed. It also has another good point, as it permits the inclusion in the expression for weight-brake of all elements besides the pressure at the shoes, which influence the intensity of the actual braking. These elements are the time to fill the brake cylinders and a factor permitting the estimation of the form of the curve representing the law of variation of pressure in the function of time. These various points will be discussed later.

The replacement of the braking force Q by the weight-brake, will be represented by the letter B in the calculations for stopping distances, and consequently transforms the classical formula by the following process :

The quantity αf or $\frac{Q}{P} f$ is replaced by $\frac{B}{Pk}$ it being understood that $B = Q.k$. k is a coefficient of the approximate value of 10/7 for wagons, 10/8 for carriages and 1.1 for locomotives.

The term $\frac{B}{P}$ will be called « percentage of weight-brake » and will be represented by the letter b, therefore, let $\frac{f}{K} = m$, expressed in kg/t brake, which is the *specific average retarding force* developed during braking between the initial speed V and stopping.

How can the terms k and m be determined? We know that for any speed :

$$f_p = f_{16} \sqrt[3]{\frac{16}{p}}$$

in which f_{16} represents the value of the coefficient of friction at the pressure of 16 kg/cm² and f_p that which is obtained for the pressure of p kg/cm².

If it is admitted by *definition* that the weight-brake of a vehicle, the shoes of which have a pressure of 16 kg/cm², is equal to the force exerted on these shoes, that is equivalent to admitting that in the formula : $B = Q.k$, k equals one if p is equal to 16 kg/cm². Therefore according to the formula mentioned above, k equals 2 if p equals 2 kg/cm². To find the intermediate values of k it is sufficient to consult the table below, which has been drawn up in accordance with the formula :

$$k = \sqrt[3]{\frac{16}{p}}$$

Pressure	2	4	6	8
k	2.0	1.59	1.39	1.26

Pressure	10	12	14	16
k	1.17	1.104	1.045	1.0

Therefore, since $m = \frac{f}{k}$, it can be seen that the retarding force m is tied to f_{16}, that is to say, with the value of the coefficient of friction for the pressure of 16 kg/cm². Consequently, all calculations in which the retarding force m appears can be resolved when the values of f_{16} are known. These are found in the last column of the table given on page 734.

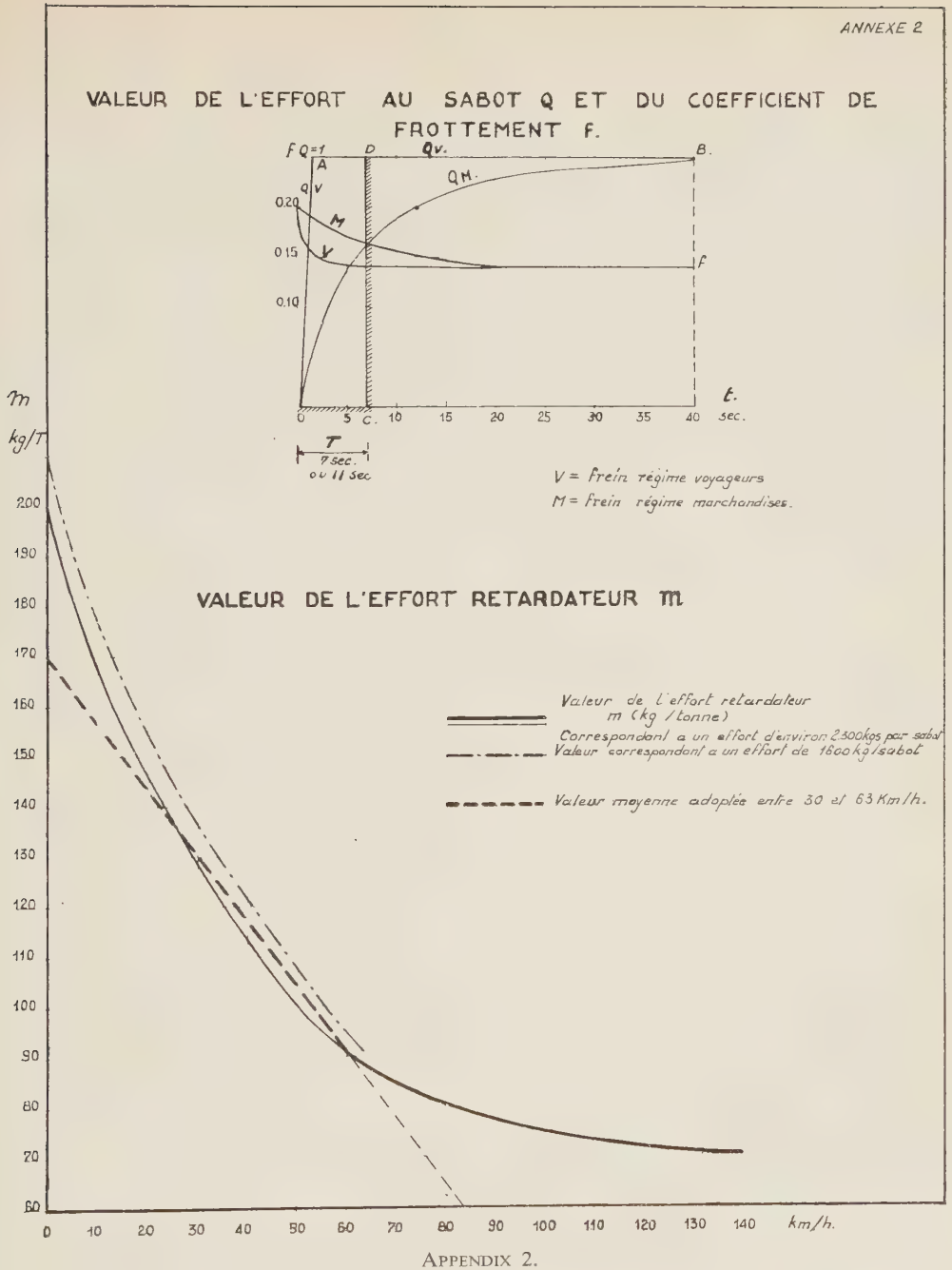
III. Variation of pressure at the shoes in function of time. Passenger and goods trains.

Up to the present, it was supposed that

the braking force applied to shoes exerted its whole effect from the initial moment when the driver applies the brake. Actually, and indeterminate period elapses between the moment when this action is carried out and when the brake shoes are applied against the wheels with maximum force. With passenger trains this time is very short (1 1/2 to 3 seconds). On the other hand, with goods trains this time is much longer, (approximately 40 seconds). Experience has shown that although there does not appear to be any disadvantages when the maximum force is immediately applied to a relatively short train, all the vehicles being braked, e. g. a passenger train, the same is not the case for a goods train. This latter is composed of a much larger number of vehicles, some loaded, some empty. Amongst these, some are fitted with brakes, others simply with a « through pipe ». As the couplings on a goods train must withstand much greater snatch, it is considered that braking should be *progressive* and, preferably, in two parts. With the first, application having a delay of about 5 seconds, the shoes are applied against the wheels with a reduced pressure approximately 1/5th of the maximum pressure. The pressure rises in accordance with a parabolical law, attaining its maximum value at the end of a period carrying with the braking system, but which is round about 40 seconds.

When it is necessary for wagons to be marshalled indiscriminately in goods, and passenger trains, or express freight trains the latter being fast trains with a reduced number of vehicles, they are fitted with mixed brakes that is to say, a brake which, by a simple lever arrangement can be changed from « goods » to « passengers » position. It should be noted, however, that in the « passenger » position pressure is not exerted by the shoes with the same rapidity as with coaches. The U. I. C. regulations lay down that for international traffic « passenger » brakes must have a maximum pressure exerted within 8 seconds.

This variation of pressure to the shoes during braking introduces an additional complication in the calculations for stopping distances. As is shown in the diagram, appendix 2, to each value of the pressure there is a corresponding different value of the friction coefficient which varies with the speed. The friction force at the shoe F consists of the product of three factors : $F = p.f.S$, of which S only, the surface of the shoe, is constant. It is of course, evident that the braking efficiency of a vehicle braked in accordance with « goods » type lessens as the duration of the brake application decreases. Consequently, when a stop must be made over a very short distance the period of braking can become much less than the time required to obtain the maximum force at the shoes and the percentage of weight-brake necessary is relatively higher than when a longer stopping distance is available. The conclusion is, therefore, reached that if, for a passenger train, the value of the average retarding force m can be considered as independent of the stopping distance within fairly wide limits (600 to 1 600 m) (656 to 1 750 yards) it would not be the same for a goods train. This circumstance has been a serious obstacle in the determination of stopping distances for goods trains and has added considerably to the



Appendix 2.

Explanation of French terms :

Value of the force at the shoe Q and the coefficient of friction F.
V = passenger type brake.
M = freight type brake.
Value of retarding force m.
——— Value of retarding force m (kg/t) corresponding to a force of approximately 2 500 kg per shoe.
—·—·— Value corresponding to a force of 1 600 kg per shoe.
– – – – Average value adopted between 30 and 63 km/h.

complication of regulations used to determine the weight-brake of vehicles fitted with « goods » brakes. When the U. I. C. established these regulations all the elements which could influence the value of the weight-brake were taken into consideration. It was considered tightly that the time for fllling the cylinders and the value of the pressure at the end of the first period must be taken in consideration, in addition to pressure at the shoes, which is, as has been shown, the essential element to be taken into consideration in determining the weight-brake. This latter is therefore given by the formula :

$$B = p.n. \frac{10}{7} \gamma$$

in which B is the weight-brake of the vehicle;

p is the force on a shoe, measured during running i. e., taken to equal 9/8 of the force, measured when stationary without straining the brake rigging;

n is the number of shoes per wagon;

γ is the coefficient, the average value of which is equal to unity, but which varies between 1.291 and 0.662, according to the characteristics of the brake, i. e. the pressure at the shoes, the time to fill and the value of the force at the end of the first period.

If it is justifiable to include the value of the pressure obtained at the end of the first period in the elements which must determine the weight-brake, it is necessary on the other hand to be extremely cautious regarding the influence of the time taken to fill the cylinders.

Consultation of the tables of the values of the coefficient γ published by the U. I. C. will show that the time for filling cylinders influences too strongly the value of the weight-brake. An example will show more clearly the importance of this. For a force at the shoe of 1 500 kg and a pressure at the end of the first period of 1/5th of the maximum pressure, the coefficient value is 1.047 if the time of filling is 28 seconds, 0.911 if this period is 44 seconds and 0.805 for a period of 60 seconds (an extreme case when the triple valve is mounted on the locomotive). Consequently, if the coefficient γ is extended to brakes on passenger trains, this coefficient will reach values greater than 1.2 in the example mentioned above. This shows that the tonne-brake «goods» represents approximately 70 % of the value of the tonne-brake « passenger ». This 70 % however, corresponds to a particular case implying a pre-determined speed and braking distance.

As will be seen later, a tonne-brake goods can, at high speeds and for short stopping distances, only represent 20 % of a tonne-brake « passenger », whilst it would be equivalent to 96 % of that tonne-brake « passenger » at low speeds and on long braking distances. This shows an element varying as much as the coefficient γ figuring in the formula of the U. I. C., which should not be embodied in the value of the weight-brake.

The most difficult problem to resolve in order to use the same formula to calculate the stopping distances for both « goods » and « passenger » brakes, is to be able to evaluate as accurately as possible the « loss of efficiency » resulting from the progressive application of pressure, which we will call the « delay ». This « delay », expressed in seconds, will

be of an assumed figure and will incorporate not only the parabolical form of the curve of the momentum, but also the decrease in the braking coefficient when the pressure increases. This is shown in Appendix 2, friction resulting from the application of the force Q multiplied by the coefficient f can be replaced by a force Q_{max} multiplied by the corresponding value of f, so long as this force is assumed to act after a *delay* of T seconds.

This delay can be assumed to be 11 seconds for « goods » brakes the filling of the brake cylinders of which is carried out in 40 seconds.

For mixed brakes working in « passenger » position, as well as for « ordinary action » brakes with which certain coaches are equipped, there is a lesser delay which is not negligible, with regard to « rapid-acting brake », with which passenger vehicles running on certain railways, especially in Belgium, are fitted. This delay can be evaluated at one second.

It should be noted that this assumed delay can, for example, reach 15 seconds for a locomotive, the brake cylinders of which fill in 60 seconds and which will drop to seven seconds for a brake, the cylinders of which take 28 seconds to fill (the lowest limit permitted for international traffic).

It will now be seen how the classical formula established for rapid-acting brakes can be altered so as to permit the calculation of the percentage of weight-brake necessary for passenger, express freight and ordinary goods trains when there is a known stopping distance and initial speed.

IV. Establishing a formula applicable to all trains and giving a percentage of weight-brake necessary for different speeds and various stopping distances.

What is going to be shown regarding the delayed action of certain types of brake will enable the customary formula to be altered :

$$L = \frac{4.24\ V^2}{mb + r - i}$$

(i being the gradient of the line in mm/m).

It will be sufficient to add to this stopping distance the length L′ corresponding to the time lost T before the maximum force is felt.

This length L′ will be equal to $\frac{V}{3.6}T$.

Let $\frac{T}{3.6} = x$, then the formula will become:

$$L = \frac{4.24\ V^2}{mb + r - i} + xV,$$

from which :

$$mb + r - i = \frac{4.24\ V^2}{L - xV}$$

$$b = \frac{\frac{4.24\ V^2}{L - xV} + (i - r)}{m}$$

The solution of b is therefore possible by this formula. However, to ascertain by what amount the value of the retarding force m is affected by the delayed action of the brake, this formula can be altered by multiplying throughout by $\frac{L - xV}{L}$. It should be noted that, for gentle gradients, the quantity $i - r$ is very small in relation to other figures in

the formula. The following is finally obtained :

$$b = \frac{\frac{4.24\ V^2}{L} + (i - r)}{m\,\frac{L - xV}{L}}$$

These are the values of the denominator of this fraction which have been shewn in Appendix 3 both for « goods » brake and « passenger » brake. The curves shewn in this graph enable the existing relationship between a tonne-brake « goods » and a tonne-brake « passenger » to be calculated for a pre-determined speed and stopping distance. Thus : for the speed of 80 km/h and the stopping distance of 800 m the following is found :

$$m\,\frac{L - 0.3\ V}{L} = 77$$

for « passenger »,

$$m\,\frac{L - 2\ V}{L} = 64$$

for « goods » (where T = 7 sec.).

The relationship « goods »/« passenger » is, therefore, 64 : 77 = 0.83.

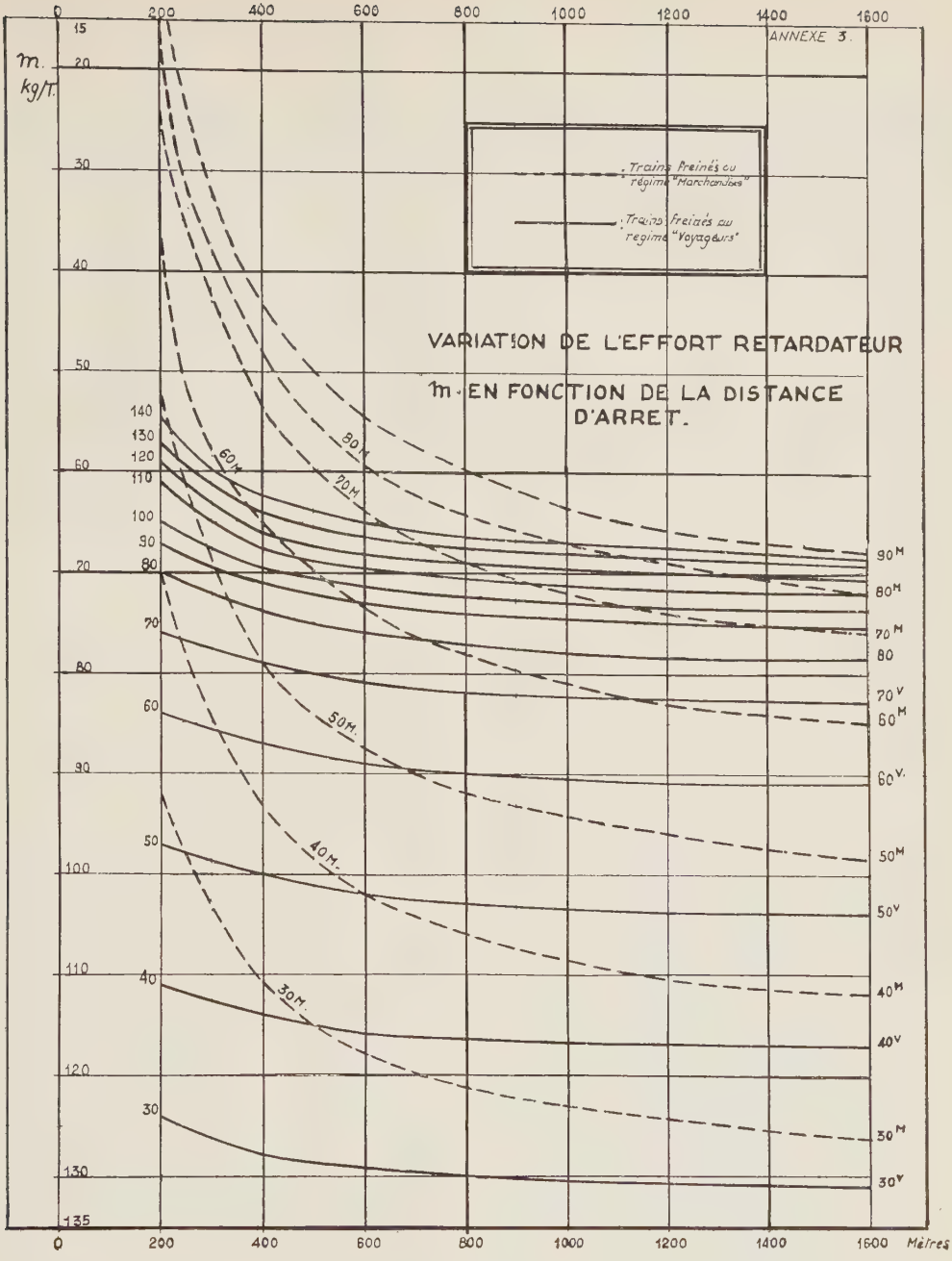
At the speed of 50 km/h and for a stopping distance of 1 200 m this relationship will be higher, 96 : 104 being obtained, i. e. 0.92. On the other hand, if the stopping distance is reduced to 400 m for example with a speed of 60 km/h, the relationship « goods »/« passenger » decreases appreciably to 65 : 87 = 0.75. Also, for very short distances, i. e. 200 m this relationship becomes very much reduced even at low speeds 92 : 124 = 0.74 at 30 km/h and 15 : 70 = 0.214 at 80 km/h.

It should be recalled that in its last form, the formula giving the value of b is no longer applicable if the gradient is very steep. Ir was agreed that the term $i - r$ was weak compared to the others, that is to say, when m is about 60 to 120 then the other side is $\frac{4.24\ V^2}{L}$, when it is assumed that V is not too small and L not too large. However, on lines having a steep gradient V is reduced and L increased, so that the values of b do not become negligible for the formation of trains. This argument shows that lines having steep gradients must be treated separately. As regards what is a steep gradient, that is a very difficult question, experience showing that for braking, a continuous gradient of 10 mm/m (10 ‰) for 10 km can constitute a greater danger than a gradient of 25 mm/m (25 ‰) for an appreciably shorter distance.

Regarding the values of m and r, which are in the above-mentioned formulae. In the first place, it should be recalled that they deal with average values chosen between starting and stopping.

Concerning the value of r, resistance to running, safety precautions lead to a too low value being taken in relation to the real, or calculated values, which are used to determine the drawbar resistance of a train.

A value representing an acceptable compromise between the various possible compositions of a train must be chosen. Two extreme cases are taken, a passenger train with few coaches (a locomotive drawing three or four coaches) and, a goods train composed of sixty or even more vehicles. In old formulae used to determine the stopping distance of goods



APPENDIX 3.

Explanation of French terms :

– – – – Trains braked by freight type brake.
———— Trains braked by passenger type brake.
Variation of the retarding force M plotted against stopping distances.

trains fitted with hand brake, this problem was solved very simply by reckoning on a uniform resistance of three kg/t. Regarding passenger and express freight trains, the composition of which is more uniform, the formula has been chosen previously :

$$r = \frac{V}{20} \text{ kg/t}$$

Regarding the value of m (average retarding force), it is proposed that for the particular case of trains braked according to « passenger » (but not rapid acting)

$$m = 57.5 \frac{V}{V - 20}$$

it being understood that this formula only applies between the speed limits of 70 to 140 km/h. These values were proposed by the appropriate Sub-Committee at the U. I. C. Conference in Amsterdam in February 1948 and were approved by the main body of that organisation. Lack of opportunity and the opposition of two railway Administrations whose regulations required less percentage of weight-brake than those given by this formula alone delayed its publication. However, the proposed law of variation for the retarding force gave the exact stopping distances found during the brake trials carried out on one of these two railway systems. These same trials also served as the basis for the work of the U. I. C. to determine as accurately as possible the most nearly exact weight-brake to be assigned to vehicles braked according to « passenger ». The U. I. C. reached the conclusion that a train running at 100 km/h on a level track has 52 % of weight-brake if it stops within 100 m and 80 % of weight-brake if it stops within the same distance from a speed of 120 km/h. These two figures had served as the basis for the formula established with a view to standardising the brake regulations of fast freight trains under international regulations. Regarding the weight-brake of vehicles braked according to « passenger », the U. I. C. indicate a method of calculation which can be used by railway systems which cannot carry out brake trials. It is sufficient for these railway systems to apply the formula :

$$B = P.k$$

in which :

B is the weight-brake;

P the sum of the force at the shoes of the vehicle;

k a coefficient of which the values are given below and which varies with the function of P/n, n being the number of shoes per vehicle.

Values of P/n (kg) . .	750	1 000	1 500	2 000
Values of k	1.58	1.50	1.37	1.27

Values of P/n (kg). . .	2 500	3 000	3 500
Values of k	1.19	1.13	1.10

This table is similar to that given on page 739 where the coefficient k had the same significance, but where the values of the pressure at the shoes were expressed in kg/cm². Comparison of the two tables shows that for the same pressure the values of k given by the U. I. C. are a little less than those now proposed, which is natural as the U. C. I. values are intended for railway Administrations who must determine the weight-brake of their vehicles by *calculation* and not by trials.

The problem to be solved, in order to find a brake formula applicable to *all trains*, was the choice of the values of m and r which were consistent with the conclusions reached by the U. I. C. when fixing regulations for the determination of weight-brake of vehicles braked under « passenger ». The first task consisted of determining a law of variation for the average values of m from every initial speed. As the value 57.5 $\frac{V}{V\text{-}20}$ had been recognised as appropriate for speeds between 70 and 140 km/h for trains braked under « passenger » (ordinary acting), it was sufficient to modify it in order to take into account the improvement obtained by *rapid acting*. It is estimated that the replacing of 57.5 by 60 in the above-mentioned formula is acceptable. For speeds lower than 70 km/h the choice can be made between determination by integration or by the graph of the value of the average retarding force due to the variation of m shown on page 739; that is to say, in taking the values corresponding to f_{16} on the curves shown in Appendix 1A. With a view to simplification, however, an approximate law, preferably linear, could be used taking into account the results of trials as well as the actual values found in practice for the amount of the retarding force at low speeds.

The choice of this latter solution, which is more simple, led finally to the values of m represented by the curve shown in the lower portion of Appendix 2 being decided upon.

Regarding the values to be chosen for the running resistance r, which also entered the brake formula, the form for passenger trains $\frac{V}{20}$ could not be used. As a compromise between the values generally used for goods and those for passenger trains had to be reached,

$$r = 2 + \frac{V}{40}$$

was adopted, therefore, as a general formula.

This formula gives $r = 3$, a figure which has been used for a long time for goods trains running at 40 km/h, and it gives slightly poor results, and therefore consistent with safety, for passenger trains running at high speed. For speeds of 100 km/h, $r = 4.5$ instead of 5 which was found by the formula $r = \frac{V}{20}$ should be used.

V. Graph for the determination of the percentage of weight-brake required in trains to stop in a given distance from a pre-determined speed.

Although the formula given on page 743 to calculate the percentage of weight-brake b, to stop a train in a distance L when running at speed V km/h, is relatively simple; fairly long calculations are involved when both the maximum speeds and stopping distances are concerned. Actually, on the Belgian Railways, for example the distances at which warning signals are placed, which are generally taken as stopping distances for brake regulations, vary with the gradient and with the nominal speed of passenger trains running on the line. The nominal distance is, in effect, 800 m for lines where passenger trains do not exceed a

speed of 100 km/h; it is increased to 1 000 m for speeds of 120 km/h and to 1 200 m on lines where the the trains can attain a maximum speed of 140 km/h. To these distances which can be used for gradients equal to or less than 5 mm/m (5 °/₀₀) a distance of 20 m is added (when V = 100 km/h) (or deducted for up gradients) or 30 m (when V = 120 km/h) for each millimetre per metre of gradient above 5 mm/m. If the field of application of the formula is within the limits of ± 15 mm/m. there are about 30 possible values for the stopping distance to be considered.

In some cases much shorter stopping distances must be used, especially when running at low speeds, on a section of the line necessitating the placing of signals at very short distances. A good example are trains running in the Nord-Midi Junction (V = 50 km/h, L = 250 m).

The range of speeds (20 — 160 km/h) and the large variation found in the values of stopping distances justify the plotting of a nomogram which enables the solution for varied conditions to be obtained.

The nomogram with points in a straight line, given in Appendix 4 gives the answer to various cases which can arise for both goods and passenger trains (1).

The method of plotting is given before describing how it is used.

The numerator N of the formula :

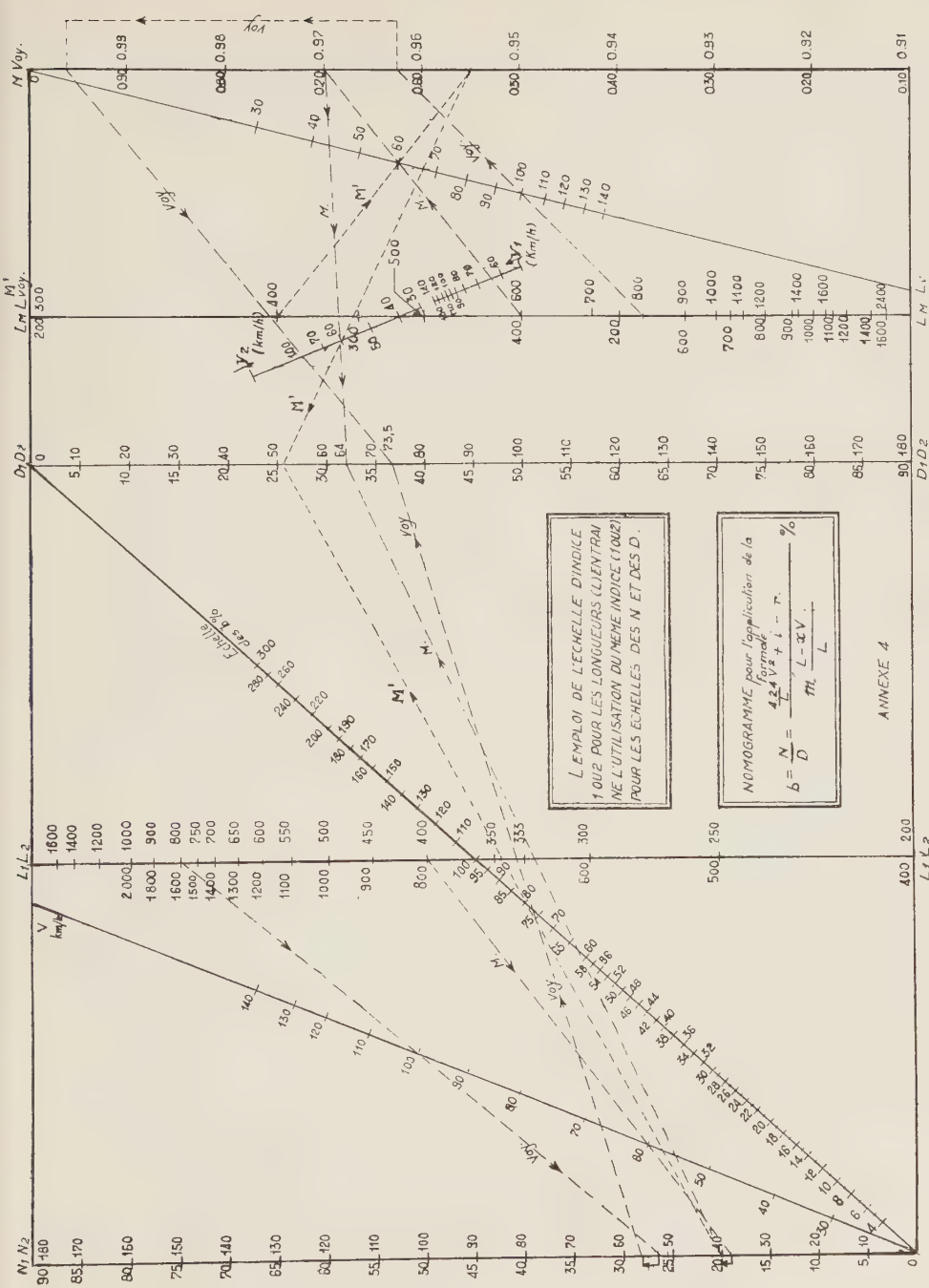
$$b = \frac{\dfrac{4.24\ V^2}{L} + (i - r)}{m\ \dfrac{L - xV}{L}} = \frac{N}{D}$$

is plotted in the left hand portion of the nomogram, whilst the denominator D is calculated in the right hand portion. The value of b can be read on the inclined scale of b percentages which join the ends of the vertical scales of the values of N and D. These values of N and D are themselves the result of a division made graphically on the values of 4.24 V^2 and $L - xV$ respectively, which must be divised by L. Regarding the quantity $L - xV$, this is also obtained graphically on two different scales, one corresponding to goods trains ($x = 2$), the other to passenger trains ($x = 0.3$). If the value T = 11 sec. is adopted, the « passenger » scale of distances can also be used for goods trains because then $x = 3$ in place of $x = 2$.

So that the nomogram is not further complicated, the addition of the term $(i - r)$ to the numerator has not been resolved graphically. This term must therefore be added to the appropriate scale (scale N_1 or N_2, according to the choice of L_1 or L_2 for the stopping distances) to the value obtained by the intersection of the « N » scale by the straight line joining the point representing the stopping distance L to that corresponding to the initial speed (inclined V scale).

One of the examples shown in Appendix 4 is a passenger train which must stop in 800 m (L_2) from a speed of 100 km/h. On the N_2 scale, the value 53 is found, which must be increased by $(i - r)$. However, $r = 2 + \frac{V}{40}$, that is to say 4.5. If the gradient is 8 mm/m (8 °/₀₀) $i - r = 8 - 4.5 = 3.5$. The point 56.5 which will be the value of N.

(1) A simplified nomogram is given in the addendum.


N Voy.
M' Voy.
Lm Voy.
D1 D2
L1 L2
N1 N2
V km/h
Échelle des D
L'EMPLOI DE L'ECHELLE D'INDICE 1 OU 2 POUR LES LONGUEURS (L) EST NECESSAIRE POUR L'UTILISATION DU MEME INDICE (1 OU 2) POUR LES ECHELLES DES N ET DES D.
NOMOGRAMME pour l'application de la formule
ANNEXE 4
Lm L'

APPENDIX 4.

Explanation of French terms :

When scale 1 or 2 for distance (L) is used the same index (1 or 2) must be used for N and D scales.
Nomogram for the formula.

How is the value of the denominator D determined in the example? The point L = 800 (Scale L_{voy}), and V = 100, having been marked in their respective scales on the right hand side of the nomogram, the straight line drawn by these points converges on the «passenger» scale on the extreme right at the point 0.9625, which represents the value of the fraction $\frac{L-xV}{L}$. Following these operations, this value, 0.9625 must, as is shown in Appendix 4, be carried over to the neighbouring scale marked » M », at a point which will be the beginning of the straight line passing through the figure 100 of the V_2 scale and reaching the value of the denominator (73.5 on the D_2 scale).

Finally, the value of the *b* percentage will be obtained by the intersection of the straight line (N_2 = 56.5) (D_2 = 73.5) with the inclined *b* scale. It is found that *b* = 77 %.

Taking a goods train running at 60 km/h and which must stop in 400 m on a gradient of 5.5 mm/m, the stopping distance can still be read on the L_2 scale. At the intersection of the straight line joining the point L (400) and V (60) with the N_2 scale, the figure of 38 is found which must be increased by $i - r$, that is to say, 5.5 — 3.5 = 2. The value of N is 40.

As the « goods » brake used corresponds to a retardation T equal to 7 or 11 seconds (x = 2 or 3), the curve marked M or M′ will be drawn on the right hand side of the nomogram. In the first case, LM = 400 m, $\frac{L-2V}{L}$ = 0.70, is obtained successively. This latter point, joined to the figure 60 on the V_2 scale gives 64 on the D_2 scale, 62.5 % is obtained on the *b* inclined scale.

In the second case, the length H = 400 is found on the same scale as that used for passenger trains. Then $\frac{L-3V}{L}$ = 0.55 is obtained. This last point, joined to the figure 60 on the V_2 scale, this time gives 51 on the D scale. The percentage required, therefore, becomes 78.5.

Is is recommended that the scales shown by means of index 1 be used for low values of the numerator N, caused by long stopping distances or running at very reduced speeds.

When the nomogram is being used for a train with rapid acting brake, the coefficient x becomes nil and the value of *m* is obtained by joining the point 0 on the V scale (right hand side) to the desired point on the V_1 or V_2 scales. The value of *m* is obtained, as in preceding cases, by finding on D_1 or D_2 the figure at the intersection of this scale with the straight line joining the point 0 to the correct point on the V_1 or V_2 scale.

VI. Solving the equation of the movement of a braked train by graph.

The establishment of the formula given on page 743 and its graphical solution as shown in Chapter V, supposes two conditions which are now restated. In the first case, it has been assumed that the gradient of the line in question would not exceed 15 mm/m (15 °/₀₀) and it has been assumed that average values of the quantities *m* and *r*′ (averages between starting and stopping) are known.

The values chosen, particularly for the quantity *m*, have been those found

through experience and used as a basis by the U. I. C. for the preparatory work in connection with the standardisation of brake regulations. It is now proposed to show how these values of m can be calculated, from the curves giving the different values of m in relation to speed.

With this end in view, the well-known formula for the equation of movement was taken :

$$F = Mj$$

in which j represents acceleration which is obviously negative in the case of braking. However, in the case of lines with a steep gradient, the lower brake force applied to goods trains during a first period during which acceleration is positive (effect of the gradient). The speed begins by increasing and, as braking is relatively weak, the speed of the train decreases very slowly and this phenomena gives the driver the impression that the brakes are not working.

The movement equation is therefore written, in the case of a train :

$$M \frac{dv}{dt} = -\left(fQ + \frac{P}{1\,000} r - \frac{P}{1\,000} i \right)$$

(i represents the gradient in mm/m).

In order to bear in mind the inertia of the revolving masses it is written :

$$M = \frac{1.088\ P}{g}$$

where :

$$\frac{dv}{dt} = -\frac{g}{1.088} \left(1\,000 f \frac{Q}{P} + r - i \right)$$

or

$$1\,000 f \frac{Q}{P} = mb$$

therefore we have

$$j = \frac{dv}{dt} = -\frac{mb + r - i}{110}$$

then :

$$dt = -\frac{110\ dv}{mb + r - i}$$

By integration, the time t which is necessary to stop the vehicle can be calculated, and the stopping distance is given by the formula :

$$L = v_o t + \frac{jt^2}{2}$$

But the integration of the formula :

$$dt = -\frac{110\ dv}{mb + r - i}$$

will be fairly difficult if m is expressed as a function of v. This integration can be relatively simple if it is agreed that m varies linearly with v (Doyen formula). The integral comprises the Napierian logarithms. If a hyperbolic law of variation is adopted (e.g. Parodi-Tetrel formula), the integral divides into two terms still containing logarithms. Finally, if, as proposed on page 739 a law in which the speed appears in the form of a cube root is used, the expression dt leads to a term of which the integration is very laborious.

In effect, if it is agreed that the law of variation is

$$m = 55 \sqrt[3]{\frac{160}{V}} \quad \text{or,} \quad m = \frac{195}{\sqrt[3]{v}}.$$

whilst the running resistance r is itself a function of speed according to the law $r = 2 + \frac{V}{20}$ (if instantaneous speed,

expressed in km/h, is used), or again : $r = 2 + 0.18\ v$.

After simplification the equation for the value of dt becomes :

$$dt = \frac{110\ \sqrt[3]{v}dv}{195b + 2\ \sqrt[3]{v} + 0.18\ v\ \sqrt[3]{v} - i\ \sqrt[3]{v}}$$

of which the integration implies the intervention of an equation of the 4th degree with imaginary roots.

However, as has been already shown, the laws of friction are not known quantitively, with sufficient accuracy to enable the integration of this expression to be carried out. It is for this reason that the graphical interpretation has been used, particulars of which are given below, showing it adapted to the particular problem of the equation of movement of a braked train.

Appendix 5 shows the arrangement used to determine graphically the duration of the brake application and the stopping distance by means of two successive integrations carried out by taking a polar distance OP for the times and another polar distance OQ for the distances.

The curve representing variation of m in function of speed is drawn in the first quadrant (ordinate and positive abscissae). The law adopted here is that corresponding to the opposite of the cube root but, of course, the process is applicable with other laws of variation of m in function of speed.

The graph of the quantity $mb + r - i$ will be obtained as follows :

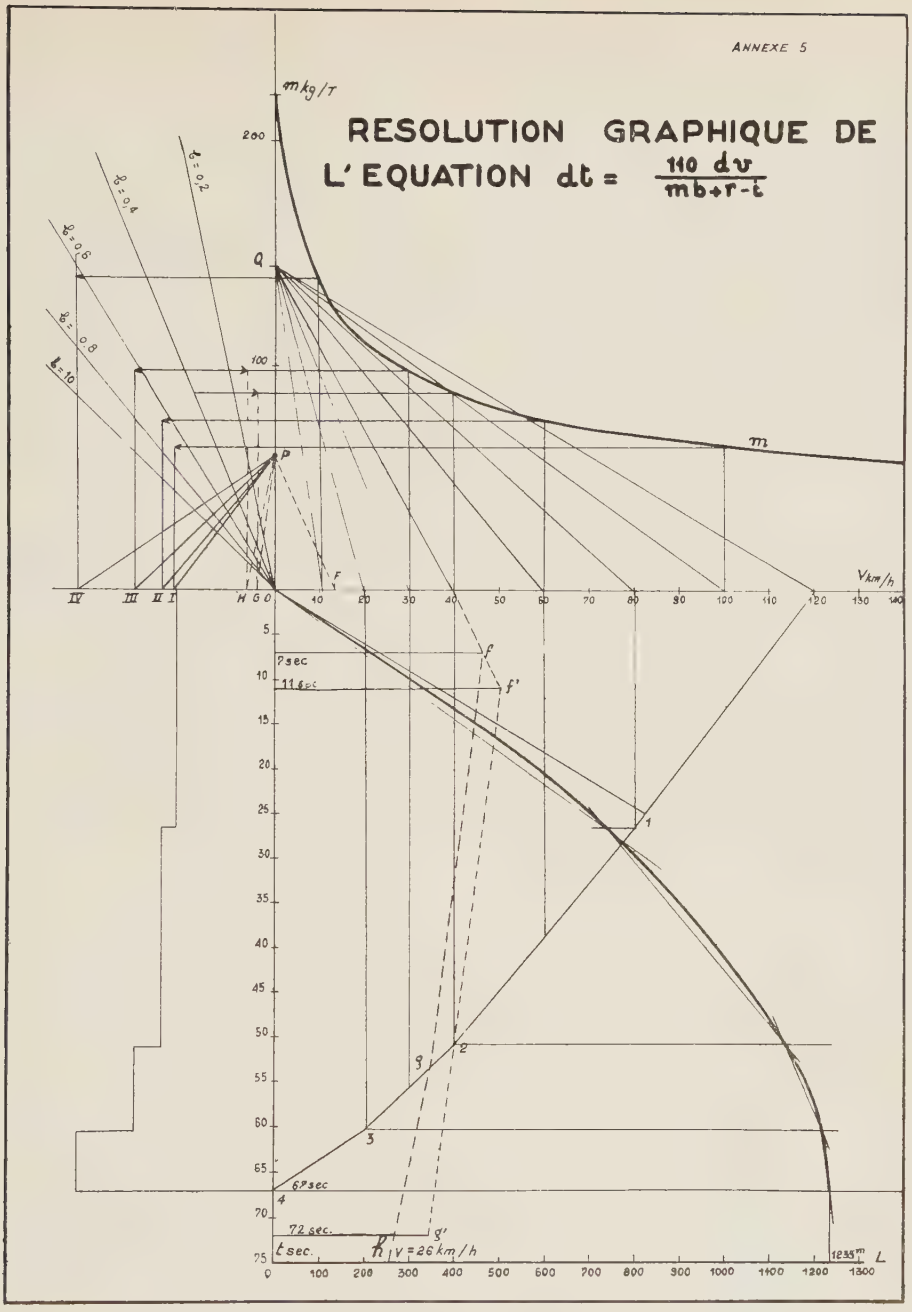
From the point 0, take a group of straight lines of which the angular coefficient equals $-b$. In order not to complicate the drawing, the straight lines corresponding to the values of — 0.2, — 0.4, — 0.6, — 0.8 and — 1, only have been shown. It will be seen immediately that for a given speed the horizontal line obtained by the corresponding point on the curve of m and produced to the oblique line for the value of b for the given train between the axis of the ordinates and the oblique line in question, is a length equal to $-mb$. All that is necessary therefore is to add to this quantity the multiples r and i with their appropriate signs. It should be recalled that the resistance r, which will be taken as equal to $2 + \frac{V}{20}$ is equally affected by the « minus » sign whilst the gradient i has a positive value for the system of axes now being considered.

It can therefore be concluded that the quantity $mb + r - i$ represented on the same scale as that used for m is carried on the axis of the negative abscissae. It is sufficient therefore in order to proceed to the graphical integration to carry the time scale on the axis of the negative ordinates.

As

$$\frac{dv}{dt} = \frac{mb + r - i}{110}$$

must be calculated, the problem is transferred to the speed curves in function of time, zero on this curve giving the braking time. In this line the primitive function is $mb + r - i$ and the integral function is v. It is known that there exists between the scales used for these curves and the polar distance OP, a relation which, in the case in question, will determine the polar distance OP, as all the other elements are known (the



Appendix 5.

Explanation of French terms :

Graphical solution of the equation :

$$dt = \frac{110\ dv}{mb + r - i}$$

scale of the v's is, actually, predetermined).

This relation is the following :

Scale of speeds =

$$110 \frac{\text{scale of times} \times \text{scale of } (mb + r - i)}{OP}$$

The drawing scale being in cm :

0.36 cm/ m/sec. =

$$110 \frac{0.2 \text{ cm/sec.} \times 0.05 \text{ cm/kg/ton}}{OP}$$

which gives :

$$OP = \frac{110 \times 0.2 \times 0.05}{0.36} = 3 \text{ cm.}$$

The polar distance OQ used for the second graphical integration, i. e. for the determination of distances, is calculated in the same manner. For distances a convenient scale is chosen, bearing in mind the range of distances under consideration, for example 0.01 cm/m.

Therefore,

the distance scale

$$= \frac{\text{Speed scale} \times \text{time scale}}{OQ}$$

or

$$OQ = \frac{0.36 \times 0.2}{0.01} = 7.2 \text{ cm.}$$

After these prelimanaries, two examples are given to illustrate the lines to use to determine graphically times and distances in connection with braking :

1) with a passenger train braked at 60 % from 120 km/h, on a level track;

2) with a goods train braked at 40 % running at 40 km/h on a gradient of 30 mm/m at the moment when braking commences.

First example :

(a) A range of speeds between 120 and 80 km/h is considered and the average value, i. e. the instantaneous value of m for the speed at 100 km/h.

The horizontal line corresponding to this value of m is produced to join the oblique line $b = -0.6$ and thus $-mb$ is obtained. This segment of straight line of a length of $r = 7$ kg/ton is produced. The vertical line is dropped and the point I on the axis of the negative abscissae is obtained. PI is drawn. The first side of the funicular polygon making up the diagram of speed in function of time will be parallel to PI. a parallel line is drawn to PI through the point corresponding to time zero and to the speed of 120 km/h. This parallel line cuts the vertical line through V = 80 km/h (limit of first interval chosen) to point No. 1 corresponding to a time of 26 1/2 seconds.

(b) The same procedure is carried out for the second interval from 80 to 40 km/h (average speed 60 km/h). Point II is obtained. The straight line 1-2 is drawn parallel to PII. The time which has elapsed since the commencement of the brake application is 51 seconds.

(c) The same operations are carried out for the third interval which is within narrower limits because of the greater variation by m in the function of speed. Point III corresponding to the speed of 30 km/h is obtained. 2-3 is drawn parallel to P III. The time is 60.5 seconds.

(d) The last interval covers the time which the train takes to slow down from 20 km/h to stop. The point IV is obtained

and the polygon of speeds is determined by the side 3-4, giving the time necessary for braking, i. e. 67 seconds.

(e) To obtain the stopping distance, it is necessary to integrate the polygon of speeds by means of the polar distance OQ = 7.2 cm. The integral curve will be a parabola of the second degree, the chords of which will be parallel to the straight lines joining Q to the points of the axis of the abscissae corresponding to the average speeds (100, 60, 30 and 10 km/h) of the chosen intervals, whilst the tangents to this parabola will be parallel to the straight lines joining Q to the points corresponding to the speeds of the extreme values of these intervals.

This parabola, the last tangent of which is parallel to the axis of time, finally gives the stopping distance, which in this case is 1 235 m.

This result should be compared with that obtained by the application of the formula :

$$L - \frac{4.24\ V^2}{0.6 \times 60 \frac{V}{V - 20} + 2 + \frac{V}{40}} -$$

where it will be found after calculation that L = 1 265 m, i. e. a difference of less than 3 %.

Second example :

It should be recalled that this deals with a goods train braked at 40 % and running at 40 km/h on a gradient of 30 mm/m.

As has already been admitted whilst studying the action of « goods » type brake, it can be admitted that the retardation corresponding to different action of the brake is 11 seconds. This determines the first interval of the graphical integration during which *mb* is nil and the only forces present are *r* and *i*. This time the quantity $(r - i)$ will be positive, and is represented by OF. A parallel line to OF is drawn through the point V = 40 km/h and constitutes the first side of the speed polygon which shows a maximum of 50 km/h at the point f_1.

If the second interval taken is that necessary to reduce the speed to 35 km/h; 40 km/h is still used but is now considered as the average.

Point G is obtained and the parallel line f^1g^1 is drawn to PG. It can therefore be seen that after only 72 seconds the speed has been reduced to 35 km/h.

On the other hand, if a retardation of T = 7 seconds is adopted, the speed diagram becomes *fgh*. The maximum obtained is only 46 km/h and the speed after 75 seconds is reduced to 26 km/h.

These examples illustrate the important role played by the more or less rapid application of the brake force whilst the train is running on a line with steep gradients. It can also be proved that when the speed diminishes as little as in the example chosen ($b = 40$ % for $i =$ 30 mm/m) the distance run can be easily determined by considering the average speed attained in the long intervals of time and a second graph (with OQ as the polar distance) as for the passenger train, is not necessary.

VII. Some particular cases of brake regulations.

The methods of calculation described enable many questions regarding the

braking of trains to be solved. They take into account the initial speed at the moment of brake application, the percentage of weight-brake, the gradient and the stopping distances, the latter usually being governed by existing signalling.

The following are worth special mention :

1) on lines having steep gradients, the problem of determining the percentage of weight-brake required to ensure sufficient brake power being available when « non-controlled release » air brakes are used (Westinghouse brake). Instead of having an initial speed to serve as a basis for the calculation of the stopping distance, there are many initial speeds and an inflexible maximum speed which the train must not exceed in order to ensure safety on curves, e. g.;

2) in case of *breakaways* on steep rising gradients the commencing speed of the rear portion of the train is zero. The stopping distance in this case must be as small as possible, otherwise it will be necessary to have a clear section behind successive trains (e. g. between a goods train and a rail car immediately following it) to ensure the safety of the following train.

When the air brake was adopted for goods trains, certain railway Administrations retained the same values for their calculations as they had used for hand brakes. These formulae are generally of the following type :

$$\% \text{ of braking} = y = \frac{i - 2}{m'}$$

2 is the running resistance for a speed of about 0. m' is an average retarding force of 140 kg/tonne, for gently rising gradients which gradually fall, or on the level, to 80 kg/tonne, when the rising gradient is equal or greater than 28 mm/m. The reduction of m' in the case of hand brake is justified by the following causes if there is a lag of, say, 30-60 seconds before the brakesmen have realised that there is a break-away and commence to apply their brakes. The train will have gathered speed proportional to the gradient and an increase in this speed will produce a corresponding reduction in the value of the retarding force applied to the brake shoes.

What are the advantages of automatic air brakes in such a situation? Time is still taken to apply the brake, but much less, 7, 11 or 15 seconds according to the type employed. Consequently, the speed the rear portion gains descending the gradient will be much less. This enables higher values for m' to be allowed, varying from 160 to 120 in place of 140 to 80. In addition, the stopping distance required can be greatly reduced, 200 m for example instead of 2 or 3 km, which was used for hand brakes on steep gradients.

The following table shows the reduction of the % of weight-brake which can be adopted for air brakes even in the hypotheses where the assumed retardation begins in 15 seconds.

The values of y for the air brake can be as given by the curve of the equation :

$$y = (i - 2) \log. 1.6 \sqrt{i - 2}$$

for the values of i equal or greater than 10 mm/m. Below this figure, the value $y = \frac{i}{2}$ can be used.

Gradient mm/m.	Value for y :	
	Hand brake	Air brake
8	5.5	3
10	8	5
12	10	6.5
14	13	8
16	15	10
20	19	14
25	25	20
30	35	26
35	41	33

3) *Goods type brakes which must be able to stop on a short distance.*

When the duration of the brake application is less than that necessary for the refilling of the cylinders, the adoption of an assumed stopping time (7, 11 or 15 sec.) will simplify calculations and will give a small error which increases according to the reduction in the duration of the brake application. It is useful, therefore, to refer to the curve giving the variation of the force applied at the shoes plotted against time (see Appendix 2). The equation of retardation is, therefore, as follows :

$$M \frac{dv}{dt} = -\left(fq + \frac{Pr}{1\,000} - \frac{Pi}{1\,000}\right)$$

in which f is the function of v and p and q functions of time.

If the value of fq is represented by unity at the moment when the maximum force is applied at the shoes, the value of fq at the various times from 0 until recharging is completed will be given by the following table :

Time	0	5	10	15	20	sec.
fq	0	0.36	0.59	0.70	0.80	
Time	25		30	35	40	sec
fq	0.88		0.93	0.97	1.0	

the average value during the 40 sec. interval is 0.73 which corresponds to nil during 11 sec. and maximum during 29 sec.

The determination of the duration of the brake application and the stopping distance can also be made by a graph similar to that shewn in the preceding chapter.

4) *Auto-speed braking applied to passenger trains.*

When passenger trains run at speeds higher than 120 km on a line where the signals are at approximately 1 000 metres apart, the weight-brake of the train must be increased to more than 80 % and may even exceed 100 %. The auto-speed brake can then be used, the principle of which is as follows : by the addition of a second brake cylinder, or by modifying the brake rigging, greater force at the shoes is obtained (e. g. double normal force) which must be limited, however, between certain speeds (e. g. between 160 or 140 km per hour and 60 or 70 km per hour). When the speed is reduced to the lower limit an automatic device cuts out the action of the second brake cylinder or the equivalent arrangement. By this means a very powerful brake application is obtained at first which is reduced as the speed of the train falls below the limit, which owing to the

increased coefficient of friction may cause the wheels to skid through too great force being applied at the shoes. Auto-speed brakes can also be used for stopping trains which have to run at a fairly high average speed not exceeding a maximum speed of 100 or 110 km per hour, as shorter stopping distances can be obtained. It is sometimes said that a carriage fitted with auto-speed brakes requires longer stopping distances than those with normal equipment when the trains are running at speeds too low for the cut-out action to operate. This difference must always, however, be very small, otherwise this would lead to a brake system not in conformity with international regulations.

Some figures are given below indicating the characteristics of auto-speed brakes and the performances which can be obtained.

If with the normal equipment a percentage $b = 80\ \%$ is obtained, the addition of a second cylinder doubling the force applied at the shoes will give, not a weight-brake of 160 %, but

$$\frac{160}{1.26} = 127\ \%,$$

1.26 representing the relation which should exist between the weight-brake of two vehicles, one of which can bring into play a force equal to half that of the other.

The weight-brake will, therefore, be 127 % from the initial speed (140 km per hour, for example), down to the speed of 60 km per hour at which figure the action of the second cylinder is cut out.

If the average value of m between 140 and 60 km per hour is taken as 62, then mb will be equal to $62 \times 1.27 = 79$. To this must be added the average running resistance, approximately 9 kg per tonne. On the level, therefore, $mb + r$ will equal 88.

Consider now speeds between 60 km/h and 0 km/h. The retarding force m equals 90 and the running resistance 3.5 kg per tonne. The quantity $mb + r$, therefore, equals $72 + 3.5 = 75.5$ in this case. The duration of the first and second periods of brake application respectively being proportional to :

$$\frac{140 - 60}{88} \text{ and } \frac{60}{75.5}$$

for the first $80 : 88 = 0.91$ is obtained and for the second : 0.7. The average retarding force, increased by the average resistance, to be taken into account for the whole of the brake application from 140 to 0 km per hour will be :

$$\frac{140}{1.7} = 82.5$$

The stopping distance will be given by

$$L = \frac{4.24 \times \overline{140}^2}{82.5} = 1\ 005 \text{ m.}$$

The introduction of auto-speed brakes complicates the weight-brake on the vehicle. In the case considered above, it would appear that the following solution must be adopted :

The normal equipment (one cylinder) corresponds to 0.8 and gives rise to the first weight-brake, but with the auto-speed arrangement the weight-brake is obtained by the following calculations :

If we subtract from the average value 82.5 appearing as denominator of the formula giving the stopping distance the value $r = 7$ kg per tonne, 75.5 is obtained.

On the other hand, the value of the retarding force m equals $\frac{60\ V}{V - 20}$, that is to say, 70 between 140 km per hour and nothing. Consequently, the division of mb, that is to say 75.5 by m (70) will give 1.08, that is, the percentage of average weight-brake produced by firstly the two cylinders and finally the single cylinder.

In consequence, if P is the weight of the vehicle, the two weight-brakes will be equal to 0.8 P with the normal brake arrangement.

1.08 P for auto-variable brake arrangement.

***

CONCLUSION.

In the introduction of the present paper the importance of the problems which the calculation of the braking of trains raises has been stressed and has shown some of the difficulties which are met when attempts are made to solve them. The aim has been to reduce these difficulties as much as possible by approximate solutions and the use of graphs.

The multiplicity of cases to be solved, the necessity to incorporate rules which are sometimes very different, owing to the diversity of the brake systems used in international regulations, has made the whole of this problem very complex and it is not pretended that a definite solution has been found to all these questions, of which the surface only has been touched in many cases.

As has already been said, it is not on the laws regarding friction that information is needed : the choice amongst so many laws and formulae proposed by responsible authors and research workers has been overwhelming, but on passing from the theoretical to the practical side, from physico-mathematical study to regulations which must be read and understood by the operating staff of the railways, much less information is available. It is above all this lack which needs filling.

Each railway Administrations interprets in its fashion results of trials in the laboratory or on the line and from these makes a more or less well chosen factor of safety; it is evident that those who wished to have some uniformity and clarity in their regulations, have found that they had undertaken a particularly difficult task.

The international organisations, such as the International Union of Railways, which have laid down the basis of regulations of an international character on the subject of the use of brakes, the characteristics to be observed, the determination of weight-brake, etc., have rendered a great service to all those responsible for laying down or modifying rules for the safe working of trains.

It is because of our own personal experience of how much the exchange of ideas between railway Administrations and standardisation of regulations fills a very real need and opens up great possibilities for improving certain sections of existing regulations that we have tried to go thoroughly into various questions which have been barely touched upon by the International conferences or are considered a delicate matter as they deal with principles or methods of calculation which have been in use over a long period.

To sum up, we hope that we have enabled headway to be made in the

solution of some of these problems and have thus contributed to reconciling points of view which are sometimes divergent when everyone, in good faith, considers that in the general interest it is the other who must make the greatest concessions.

***

ADDENDUM.

The formula :

$$b = \frac{1}{m}\left[\frac{4.24\ V^2}{L - xV} + i - \left(2 + \frac{V}{40}\right)\right]$$

which we have altered in view of the nomograph in Appendix 4, can be retained in its original form and gives rise to another nomograph more easily read and has the advantage that it can be used whatever the value allowed for the coefficient x.

The modified nomograph shown in Appendix 6 also consists of a combination of the nomographs in N of which the method of employment is described below :

1. The first operation consists of determining the length $l = xV$ to reduce the stopping distance L. It is obtained by joining the point representing speed (lower horizontal scale) to the value x (oblique scale) admitted for the type of brake under consideration ($x = 0$ for rapid action, $x = 0.3$ for ordinary action, $x = 2$, 2.5 or 3 for goods type brake). The length l is read on the horizontal scale of lengths (negative portion). $L - l$ is subtracted and the result carried to the scale of lengths (L).

2. The point thus obtained on the scale (L) will be joined to the point representing speed indicated on the *upper* horizontal scale (scale of 4.24 V^2). The result can be read on the diagonal scale (J).

Thus the quantity: $\frac{4.24\ V^2}{L - xV}$ is obtained.

3. To the quotient $\frac{4.24\ V^2}{L - xV}$ must be added the algebraic expression $i - \left(2 + \frac{V}{40}\right)$ or $i - r$. The scale of (J) not being proportional this operation cannot be made graphically.

To facilitate the calculations, the values of r in the function of V have been reproduced above in the nomograph as well as those of m (average specific retarding force).

4. The result of the operation :

$$\frac{4.24\ V^2}{L - xV} + i - r$$

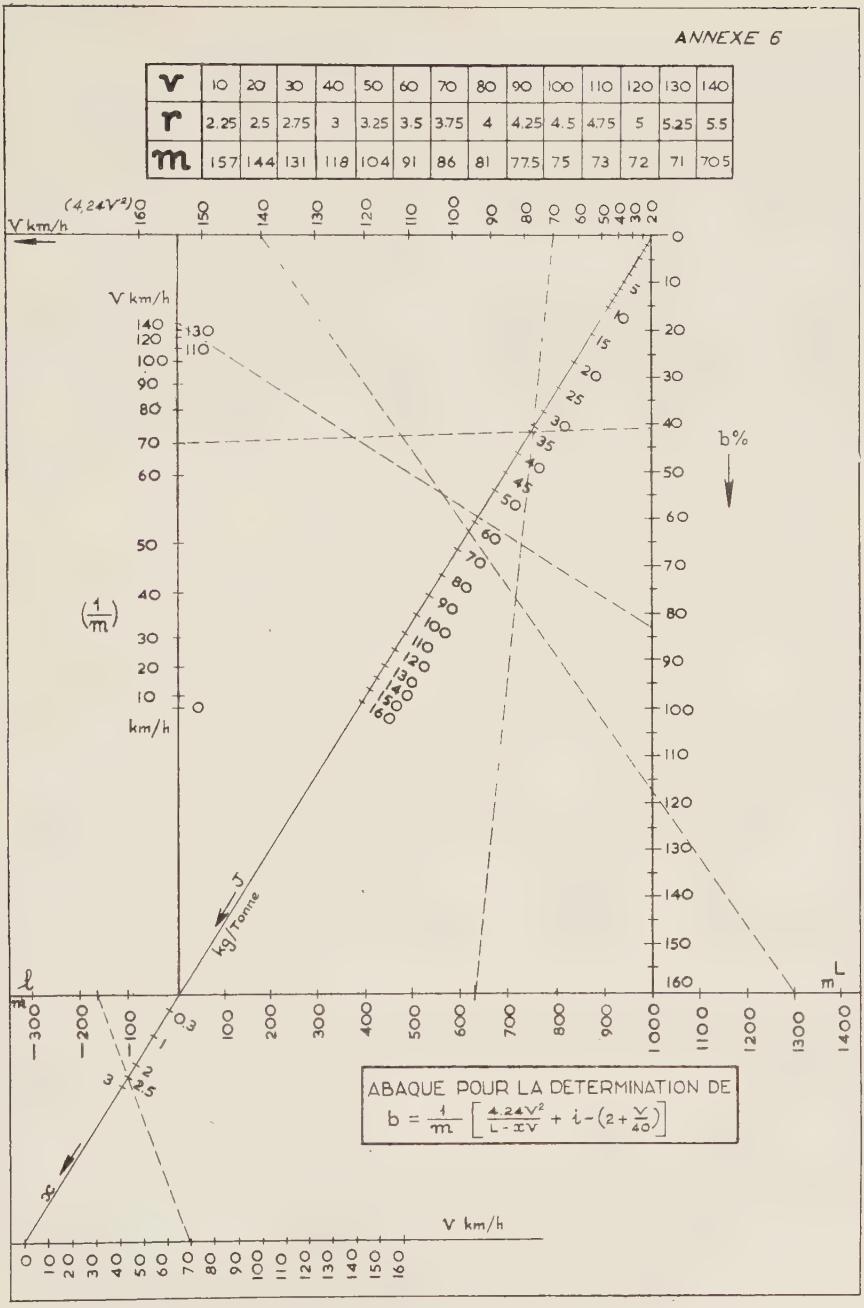
having been placed on the scale of (J), the point thus determined is joined to the point representing speed on the *lef vertical scale* $\left(\text{scale of } \frac{1}{m}\right)$. The straight line thus defined meets the vertical scale of the *straight* line (b) at a point which gives the percentage of b.

EXAMPLES.

I. Let us suppose that we are looking for the percentage b needed to stop a goods train within 800 metres on a gradient of 5 mm per metre ($x = 2.5$) running at 70 km per hour.

1. The first operation is to show 625 metres on the scale of L.

2. The second operation, which consists



V	10	20	30	40	50	60	70	80	90	100	110	120	130	140
r	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25	5.5
m	157	144	131	118	104	91	86	81	77.5	75	73	72	71	70.5

APPENDIX 6.

Explanation of French terms :

Nomograph to solve....

of joining the point 625 metres to the point 70 on the upper horizontal scale will give 33 on the scale of (J).

3. $(i - r)$ must be added, that is to say, $5 - 3.75$ or 1.25 to the figure 33 previously obtained, which gives 34.25.

4. Joining 34.25 (J) to 70 on the scale $\frac{1}{m}$, 40 % is obtained on the scale b.

II. To find the necessary percentage to stop using rapid action brake on 1 300 m, a train running on level ground at 140 km per hour.

1. As $x = 0$, L = 1 300 m.

2. V = 140 is joined to the upper portion and 64 is obtained on the scale (J).

3. 5.5 is subtracted from 64 and 58.5 is obtained on the scale (J).

4. 140 is joined to the scale $\frac{1}{m}$ at 58.5 on the scale (J) and $b = 83$ % is obtained

[656 .21 (73)]

Retarders and intensified supervision cut switching damage to equipment and lading,

by C. E. McCarty,
Manager, Potomac Yard, Richmond, Fredericksburg & Potomac.

(*From the Railway Age.*)

At Potomac Yard, Alexandria, Va., a determined effort on the part of the management to reduce the amount of physical damage to freight cars during yard classification has resulted in a reduction of about 87 % in such damage, with, it is believed, a corresponding decrease in injury to the lading of those cars.

We realized early in our campaign to reduce damage to cars in classification that any study must include a report, prepared as early as possible after the completion of the day's work, showing information necessary to trace the source of damage. For that purpose a report was inaugurated showing : (1) the initial and number of each car found damaged in the classification yard after having passed, without exceptions, the initial inspection on arrival; (2) the number of the track in which it was found; and (3) the extent of damage. This report is on the writer's desk by 9 o'clock each morning, and it enables us to determine the exact time such cars are classified over the hump and so to fix the responsibility with the car-retarder oper-

TABLE I.

Cars damaged in classification

Year	Northbound			Southbound		
	Total cars classified	Total cars damaged	Cars damaged per 1 000 classified	Total cars classified	Total cars damaged	Cars damaged per 1 000 classified
1944	788 499	1 887	2.39	659 080	1 688*	2.56
1945	703 812	2 607	3.70	589 967	2 128*	3.61
1946	682 928	1 860	2.72	589 834	1 257	2.13
1947	585 715	980	1.67	534 937	591	1.11
1948	550 696	789	1.40	500 786	345	0.69
1949	503 421	242	0.48	459 738	155	0.34
8 Months 1950	335 299	137	0.41	303 364	134	0.44

* Southbound yard operated as « rider » hump prior to Oct. 22, 1945, with complete retarder classification effective Jan. 1, 1946.

TABLE II.

Cost of repairing damage occurring in classification.

Year	Total cars classified	Total cars damaged	Cost of repairs	Cost per car damaged	Cost per 1 000 cars classified
	Northbound				
1948	550 696	789	$ 9 157	$ 11.60	$ 16.63
1949	503 421	242	3 500	14.46	6.95
8 Months 1950	335 299	137	2 255	16.46	6.73
	Southbound				
1948	500 786	345	$ 4 013	$ 11.63	$ 8.01
1949	459 738	155	2 883	18.60	6.27
8 Months 1950	303 364	134	2 707	20.20	8.92

TABLE III.

Impact register tests.

As a further means of checking and controlling classification yard damage, periodical tests are made with impact registers, The results of the last two periodical checks are summarized as follows :

Period	Numbers of tests	Impacts registered by zones*				
		1	2	3	4	5
July 11-14 1950	59	9	28	12	9	1
Aug. 15-19, 1950.	66	10	29	23	4	0

* Zone 1 and first half zone 2
Second half zone 2
Zone 3
Zone 4
Zone 5

Normal handling
Borderline
6- 7 miles per hour
8- 9 miles per hour
10-11 miles per hour

ator or train crew involved. In order to keep the subject of rough handling always before those engaged in classifying cars, i.e., car-retarder operators and train and engine crews, a second report is issued daily which shows the initials and numbers of the damaged cars, time of classification and the track number and extent of damage.

These reports, coupled with daily run-

View of the southbound hump at Potomac Yard, under floodlights, showing retarders.

A portion of the southbound classification yard, seen from the hump.

(Photo by Turner Studio.)

Three cuts of cars are in motion on the descending side of the northbound hump. The first car of the cut in the immediate foreground has just entered the retarder.

(Photo by Turner Studio.)

Southbound repair track, with wheels being changed under Master Mechanic Kidwell's direction.

ning statements which are constantly followed by the writer and members of the staff, and monthly reports similar to those reproduced with this article, plus disciplinary action if circumstances warrant it, have constituted the plan under which our success has been achieved.

TABLE IV.

Summary of car damage during a recent month.

Broken couplers	4
Cars off center	9
Cars derailed	0
Train lines broken	4
Lading shifted (including cars with ends or sides bulged)	15
Doors damaged	5
End sills, center sills or end plates damaged	0
Miscellaneous	4

In addition, of course, a high standard of maintenance for the retarders and yard grades is necessary in order to provide the retarder operators with proper working tools. As a result of the better switching performance secured in this way the cost of repairs to damaged cars has been cut from more than $ 12 per 1 000 cars classified in 1948 to about $ 6.62 during 1949, and $ 7.77 during the first eight months of 1950. This is a not insignificant saving.

[625 .244 (71)]

Canadian Railways' refrigerator cars,(*)

by A. N. Campbell,
Assistant Vice-president, International Equipment Company.
(*From the Railway Age.*)

Few of us realize that 75 per cent of all the food we consume today is perishable. New York City could not subsist for more than ten days without cold-storage products. Frozen foods are now staples and more than 1 200 varieties have been put up in this way — everything from Chinese egg rolls to fresh cocoanut milk. It is claimed that this method of preservation will keep foods for centuries, as evidenced by the fact that the flesh of huge prehistoric monsters found frozen in Alaska and Siberia was discovered to be quite edible, centuries after the beasts died.

In addition to foodstuffs subject to deterioration in temperatures unsuited to their preservation, all sorts of other products must be transported under controlled temperature conditions. Valuable plant bulbs, blood plasma, flowers, live lobsters, beer, wine and canned goods must be protected as they are moved about the country. Rubber and ordinary honey bees — live bees — have been handled in refrigerator cars and the same cars have been used to ship such things as ball bearings to prevent moisture condensing on them, damaging the fine finish.

An all-steel refrigerator car showing the underslung heater. The car is one of a group of 300 50-ton cars turned out by the Canadian National Transcona shops during 1948 and 1949.

The demand for safe distribution of these commodities all over the continent has prompted the development of a railway car which will cool, keep and carry them. These cars must be capable of maintaining certain products at temperatures around zero on the hottest summer day, while other commodities must be kept at a tem-

(*) This article is adapted from a paper presented before the Toronto Railway Club of April 24, 1950.

perature above 32° when the Canadian winter reaches 45 to 60 below zero. Each commodity has a temperature at which it carries best — bananas at 60°; apples at 32°; bacon at 30°; and frozen foods at zero.

In Canada, all of the refrigerator cars are owned and operated by the railroads. In the 1930's farsighted Canadian car designers took a different approach to the shortcomings of the end-bunker refrigerator car. They chose to modernize their present ownership of the end-bunker refrigerators adhere to all of the mandatory rules and requirements of the Association of American Railroads and various laws of the United States and Canada. For example, no car of untried type can be offered in interchange until its size, capacity, and design have been approved by the Transportation and Mechanical Divisions of the A.A.R. In contemplating redesigning their refrigerator cars completely, Canadian railroad engineers had no alternative but to start out with A.A.R. standards. They

Interior of a Canadian Pacific refrigerator car. The radiator pipe is shown under the raised section of the floor rack.

and to keep them up-to-date with latest designs of this car in the United States, but to build new cars along entirely different lines.

They found this to be a difficult task. In the first place, an average of 20 000 freight cars belonging to United States railways operate over Canadian lines every day, while a like number of Canadian cars are operated on some or all of the 540-odd line-haul railroads in the United States from coast to coast and from the Gulf to the border.

The designer of the refrigerator car must used the latest types of trucks, draft gears and other running gear, all strictly in accordance with the requirements of the A.A.R. Upon these trucks they built a steel underframe and superstructure meeting all A.A.R. strength requirements, actually following closely the A.A.R. standard design of steel-sheathed box car which has proved itself capable of withstanding 15 years or more of the most rigorous railway service.

Insulation.

Inside the outer steel sheathing an addi-

tional steel shell is built, completely insulated from the outside frame by four to five inches of the best insulation obtainable. Very careful planning was necessary to avoid any metal-to-metal contact between the inside and outside metal shells. It is calculated that one bolt passing from the inside to the outside of a refrigerator car can cause a heat loss of from three to four B.t.u. per hour. In the old end-bunker cars, heat loss in this manner was calculated at 27 B.t.u. per hour, or about 20 per cent of the total heat leak through the walls, floor and roof of a car. About 28 per cent of the area of the side walls of a wood-sheathed end-bunker car was not properly insulated due to framing members occupying space which should have contained efficient insulation. Wood has more than four times the conductivity of good insulation. Therefore, the difference in heat loss between the modern Canadian refrigerator car and the old end-bunker car is considerable, explaining, in part, record savings in ice established with the new design of car. Moisture in the insulation has much to do with insulating value, hence the outside steel shell is sealed with riveted or welded joints, while the inside steel shell has welded joints which are flooded with asphalt as an additional vapor barrier.

Overhead bunkers.

Canadian engineers benefited from the experiences of a sister member in the British Commonwealth of Nations and based their design on that of cars built and operated by the South African Railways and Harbours Board. Under the insulation in the roof of the car shallow ice tanks, eight in number, are mounted so that they can be filled with ice from the roof of the car. These tanks retain a reservoir of cold brine in them even after all the ice load has melted. They hold about 7 000 lbs. of ice and salt when filled and, with a 30 per cent to 70 per cent mixture, the temperature of the melting ice is 6° below zero.

Below the ice tanks are plywood drain pans which collect any condensation which may form on the surface of the cold tanks. The drain pans nested closely together form the ceiling of the car. The side walls are composed of shallow flues covered with plywood inside lining. The floors are metal, welded at the joints so that no moisture can get down into the underframe or insulation. Floors are specially sloped and formed to clear moisture from the cars. Floor racks are designed to allow free air circulation under the load transversely, longitudinally and vertically through openings in the racks.

Under the drain pans in the ceiling of the car there are meat racks. The Canadian car is an all-purpose type designed to carry any perishable commodity ordinarily shipped by rail.

Underslung heaters.

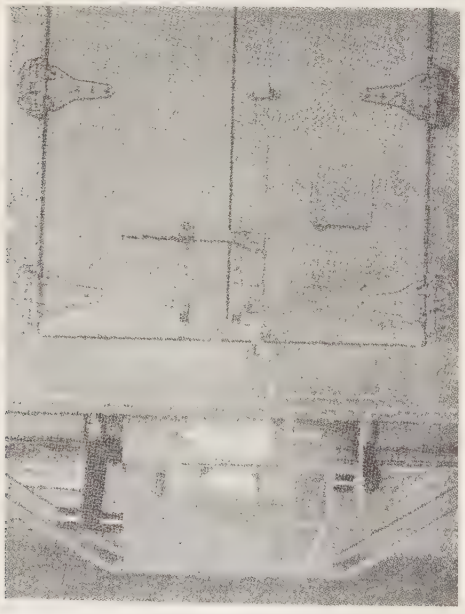
New Canadian cars are equipped with an underslung charcoal heater carried under the car where it can be quickly examined and serviced from the ground. This type of heater was developed about fourteen years ago by the Canadian railways with the cooperation of the National Research Council. The device is much similar in principle to the portable charcoal heater, but is larger and more reliable. It has a firepot with an adjustable draft control, fed automatically from a magazine above holding 50 to 60 lbs. of charcoal. Copper coils in the heater connect to heater coils under the floor racks through which anti-freeze heated in the firepot circulates throughout the car. Air, heated by the coils, rises through the load, evenly heating it by natural convection. Anti-freeze is used so that the liquid in the pipes will not freeze when the car is under refrigeration, or when it is traveling empty with no fire in the heater at Canadian winter temperatures.

With the underslung heater, the difference in temperature of lading at various locations is rarely more than a few degrees and no poisonous carbon monoxide gas is

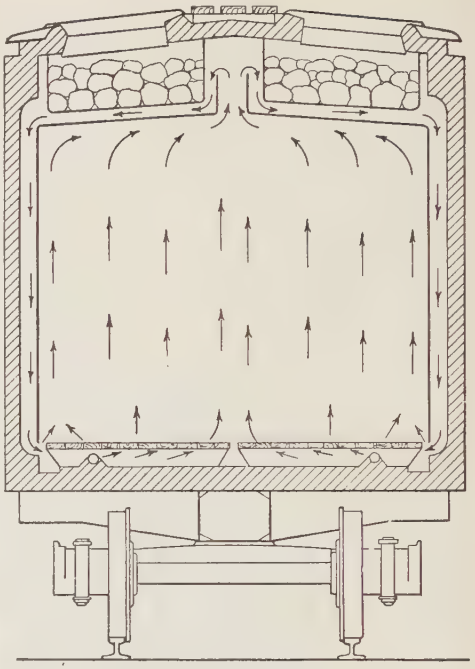
liberated in the car to damage fresh meats or inconvenience men working with the cars. Tests are now being made in Canada with a thermostatically controlled heater. Canadian railroads are proceeding cautiously; they must be sure that a device is absolutely reliable under the most unfavourable conditions which may be encountered before adopting it.

Distance-reading thermometer.

A distance-reading thermometer, located in the outside sheathing of Canadian refrigerator cars, indicates at a glance what temperature exists inside the car at the top and bottom of the load. This device is so designed that it is completely unaffected by outside temperatures or by temperatures which exist between the dials on the outside of the car and the location where the temperature determination is desired.



The outside charcoal heater under a Canadian Pacific refrigerator car. Heat is transmitted by liquid circulating through interior radiator pipes.



The air-circulation circuit in the overhead-bunker refrigerator car.

When cars are not equipped with distance-reading thermometers, it is a custom to light the heaters when the outside temperature goes down to a specified level. This is the only way protection for the load against freezing can be provided. Since the installation is not the same in all cars, heaters are sometimes lighted when they are not required and overheating damage results. When cars are equipped with thermometers which indicate temperatures of the load without opening the doors, arrangements can be made to light the heaters only when the load requires it. Conversely, readings of the thermometer on the side of the car indicate when reicing of the load is necessary in summer. Often the temperature inside a car is such that icing at some regularly scheduled icing station can be avoided. Without the thermometers, however, it is the custom to reice cars without regard for the imme-

diate requirements of the lading when the outside temperature at the time indicates that certain refrigeration protection is necessary. By the use of the distance-reading thermometers, a great deal of guesswork is eliminated.

Further refinements.

Since the original Canadian designs of overhead refrigerator cars were adopted, refinements have been added from year to year as experience and tests proved their worth. The drain traps on one type of Canadian overhead car are located midway between the center and the ends of the car to keep the drainage away from the trucks and running gear, avoiding, in part at least, some of the corrosion of these parts which results from their exposure to brine drippings in the ordinary type of car. Sliding doors, first applied for test several years ago, have now been improved and are being installed on additional cars for further tests. Still other refinements are now being studied. Canadian railroads in the past eleven years have placed in service nearly 3 000 units of the Canadian overhead type refrigerator car. They have invested over $ 35 million in them. Now let us see what they obtained for their initiative, ingenuity and investment.

The « Proof of the Pudding ».

With the end-bunker cars, about 7 ft. of longitudinal floor space — over 300 cu. ft. of the interior — is taken up by the ice bunkers and, owing to the necessity for allowing space at the sides, at the center and over the load for air circulation, only a part load of perishables can be handled. In the overhead-iced car every cubic inch of loading space can be utilized. Prior to the war the average load carried in an end-bunker car was about 35 000 lbs. The overhead-iced car is often loaded to over 90 000 lbs. and the load limit is over 100 000 lbs. In addition, it requires considerably less ice which, of course, is dead weight on which the railway gains no revenue and for which the shipper pays.

In the end-bunker car perishables cannot be loaded higher than the top of the bunker bulkhead, otherwise the flow of air is stopped and the load could not be cooled properly. Seven hundred fifty to 800 boxes of apples are carried in an end-bunker car, while the overhead car carries 1 152 boxes. The end bunker carries 550 crates of oranges, while the overhead car carries 840 crates. As against 660 egg crates in the end bunker, the overhead iced car carries 900 crates.

In addition to freight charges, the railway patron — the shipper of a perishable commodity — must bear the cost of icing and heating. Refrigeration is usually charged for according to the number of tons of ice and pounds of salt used. A large precooled or frozen load costs no more to refrigerate than a small load. The overhead-iced car requires less ice than the end-bunker car and it is common for transcontinental loads in overhead-iced, thermometer-equipped cars originating at Prince Rupert to require only one to three reicings en route, against seven reicings at regular icing stations 24 hours apart for an end-bunker car with a smaller load. Ice economies for the railway shipper may exceed $ 100 per trip.

Along with these economies both to the shipper and the railway, the overhead-iced car does an all-around better job whether the commodity requires heating, ventilation or refrigeration. The air around the tanks in the ceiling of the car is cooled and falls down through the flues behind the lining in the walls of the car. It is liberated under the floor racks and, as it picks up heat from the load, it goes straight up to the ceiling ice tanks where it is cooled again. The air needs to travel only about 25 ft. regardless of the length of the car, as against air travel of about 47 ft. in an end-bunker car.

Problems yet unsolved.

In spite of this record, the Canadian railways are not resting on their laurels; they are watching every development.

They would like to reduce the cost of building and maintaining their cars with their 500-odd different parts. They would like to be able to hold temperatures still lower at reasonable cost. They would like to be able to reduce their investment of millions of dollars in ice each year.

Canadian railroads actually use about 200 000 tons of ice each year for refrigerator cars. They buy about 300 000 tons (about 10 000 carloads) at a cost of over $ 2 000 000, as one third shrinks away before it is used. Ice is harder to obtain every year. Canada, the land of ice and snow, has found it necessary to import thousands of dollars worth of ice.

Ice alone will not produce temperatures lower than 32° F. in the coldest part of the car. Ten pounds of salt added to 100 lbs. of ice will produce a temperature of 21° above zero. Thirty pounds of salt with 100 lbs. of ice will produce a temperature of 6° below zero. The temperature in the car is, of course, somewhat higher than that of the refrigerant and the addition of a quantity of salt to ice, particularly, in an end-bunker car, is not a reliable indication of the temperature which will be obtained, as the salt rattles down through the ice to the bottom of the bunker. Residue from impurities in the ice, which runs as high as 10 per cent, forms a stone-like deposit in the drain pans and tanks of refrigerator cars. The salt further provides a problem in that it quickly corrodes car parts and causes considerable damage to tracks and bridges as it escapes in solution from the drains of the car.

Disadvantages of water-ice and salt.

As much as 2 600 lbs. of brine may drain from one refrigerator car in 24 hours. Brine drippings cause thousands of dollars worth of damage to tracks, bridges, and car parts every year. The report of the federal coordinator of transport published in 1935 estimated damage to tracks and bridges in the United States from this cause may amount to $ 420 000 per year. One Canadian railroad has tested out hundreds of types of paint in the hope of finding an inexpensive miracle product which will resist brine corrosion without greatly increasing the cost of the cars.

Canadian railroads have experimented with the use of dry ice which costs many times as much as water ice, but is about twice as efficient. Solid carbon dioxide melts at 109° F. below zero and is, therefore, difficult to transport and store. This type of refrigerant avoids difficulties with brine and reduces the dead weight of ice transported about the country. However, the gas liberated from dry ice has a bad effect on the flavor of certain perishables and a discoloring effect on certain meats.

Canadian railroads have experimented further and find that they can obtain temperatures as low as 15° F. below zero in their overhead cars with salts other than the sodium chloride (table salt) commonly used. The cost is considerably higher, however, and delays for reicing increase correspondingly.

Mechanical refrigeration.

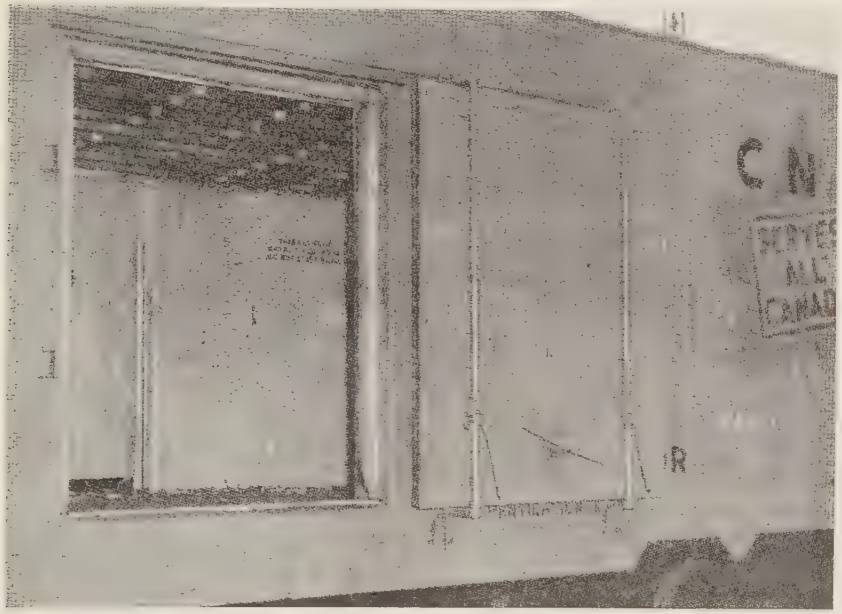
As in Canada, United States refrigerator car owners are experimenting with methods of refrigerating cars without using ice and salt. An ammonia absorption system was installed in a few cars several years ago. Ammonia carried under the car is expanded in coils inside, then absorbed by a tank of water. Special supplies and equipment for recovering the ammonia are required and further installations were not considered practical.

About 20 years ago 80 cars were placed in service equipped with a refrigeration system which depended upon the adsorption of the refrigerant by silica gel reactivated by a propane gas flame. Some of these cars were tried out in Canada. They were demonstrated as incapable of providing uniform temperatures much lower than 20° F. and, therefore, were considered to be no better than ordinary refrigerator cars.

British Columbia packers are at the present time pleading for uniform zero refrigeration which even the overhead iced car

cannot provide. The Canadian Department of Fisheries is interested and, as a result, a Canadian railroad car has been fitted up with a mechanical refrigeration system powered by two gasoline motors. This device, as far as railway operation is concerned, is still in the test stage. Its future is obscure, because the A.A.R. rules of interchange prohibit the free movement of cars equipped with machines using such fuels as gasoline, and it is doubtful if railroad insurance companies will accept the risk of operating freight cars so equipped.

Freedom of movement of railway cars equipped with machines using Diesel fuel is not affected by the A.A.R. rules. Recently a suitable Diesel engine has been developed in the United States and two cars have been fitted up with Diesel-powered mechanical refrigeration. These cars have been used successfully to transport frozen orange juice concentrate from Florida to New York and Boston. In tests, the cars were loaded at 8° below zero in 75° weather, proceeded to destination and maintained the same temperature at unloading. The United States car line operating these two test cars has now ordered ten more to be put in service this year.



The sliding door now in use on some Canadian National refrigerator cars. Installed at the Transcona shops and put in service in May, 1950.

It is obvious that, in the future, there will be new developments in the handling of perishable railway traffic so vital to the life and development of the nation and its resources. Thousands of cars are involved, however, and every new development which is adopted must show a profit — in reduced building costs; in reduced maintenance of cars, tracks, bridges or other facilities; in traffic held; in traffic gained; or in better service to railway patrons. When a device or design is proved to possess one or more of these advantages, I am confident that Canadian railways will be among the first to adopt it.

[621 .431 .72]

Performance of traction radiators,

by J. L. Koffman,

(From the *Diesel Railway Traction.*)

In a radiator, heat is conveyed from the water to the inner surface of the tubes by convection, passes through the tube walls by conduction, and finally leaves the outer surface, mainly by convection and only to a small extent by radiation. However, since « radiator » has been adopted as a label for the heat exchangers concerned, this term will be used, though « cooler » or « convector » is more logical. The most effective radiator (or more precisely radiator matrix) will be that in which heat transferred from the engine cylinder jackets is dissipated with the minimum expenditure of space and weight and of power necessary for adequate supply of cooling air. However, considerations of reliability, maintenance, and production may necessitate a compromise at the expense of some loss of pure efficiency, and many forms of matrix have been and are still being evolved in an attempt to find an optimum design.

There are in general only two basic forms of radiator : that in which water flows through a nest of tubes exposed to a cross-flow of air, and that in which air flows through tubes exposed to a cross-flow of water. The suitability of any one type for a vehicle cooling system must be judged on the basis that the ideal radiator is that which needs the smallest space and fan h.p., is mechanically robust, and not susceptible to dust externally or to water deposits internally. These requirements are at present best met by gilled tube radiators with specially shaped tubes. The continuous gill and tube matrix ensures high rates of heat dissipation at relatively low values of air pressure losses; its drawback is the possibility of water deposits clogging the tubes; this, however, can be much reduced by pressurising the system, which will reduce the amount of water lost through evaporation and avoid frequent topping-up, usually necessary with non-pressurised systems.

One type of continuous gill and tube matrix is constructed in blocks incorporating two, three, five, eight, and ten tube rows; two or more of these blocks may be used one behind the other with a gap of about $\frac{1}{2}$ in. (usually) between individual blocks. The locked seam tubes are 0·525 in. long, 0·10 in. wide and are made from 0·008 in. brass strips, and the gills are made from 0·004 in. copper strips incorporating small ridges or indentations to create additional turbulence. The front edges of the gills are turned over to stiffen them and to give a finished appearance. They are soldered to the tubes.

The flow of heat transferred from the radiator to the cooling air is given by : $\rho Q = UA\ (t_w - t_a) = UA\ \Delta t_m$ [B.Th.U./min.], where Q = rate of heat flow; U = overall heat transfer coefficient [B.Th.U./(sq. ft.) (min.) (F)]; A = radiator frontal area [sq. ft.], and $\Delta t = t_w - t_a$ = temperature difference (T.D.) between the main body of water and air (F).*

The radiator is a heat exchanger of the cross-flow type in which water and air travel at right angles to each other. The temperature of water is decreasing whilst moving through the radiator, and that of

(*) On the subject of temperature designation, Max Jacob (« Heat Transfer, » Vol. I, p. 717, New York 1949) states that the symbol °F. should be used to show a certain point in the temperature scale, whilst F should indicate the units difference on this scale. Thus, whilst 100° C. = 212° F., 100° C = 180° F., as the sign ° denotes a point in the scale, but F. or C. alone designates the number of units according to the notation (Fahrenheit or Centigrade) concerned.

the air increasing. A temperature gradient can be drawn to show the change of temperature from water to air at any specific position along the radiator, but the temperature gradients at different positions will not be alike, as shown in figure 1. The distance between the lines indicates the difference in temperatures between the two media. The changing temperatures are shown by curved lines, for it can be proved by tests and mathematical analysis that they are not linear functions of the travel along or through the matrix.

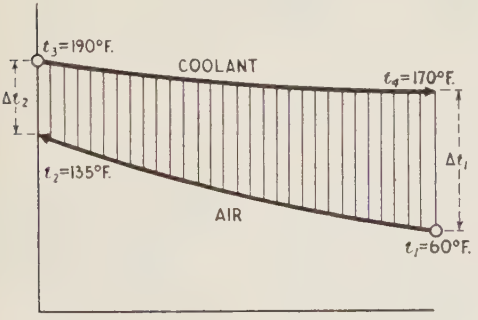


Fig. 1. — Temperature distribution.

The mean temperature difference thus is not the arithmetic mean Δt_m, *i.e.* not the average of the distance between the lines at the two ends; the true mean temperature difference is the logarithmic mean temperature difference $\Delta t'_m$.

$$\Delta t'_m = (\Delta t_1 - \Delta t_2)/[\log_e(\Delta t_1/\Delta t_2)]$$

or

$$(\Delta t_m = (\Delta t_1 - \Delta t_2)/(\log_e \Delta t_1 - \log_e \Delta t_2)$$

where :

Δt_1 = Larger temperature difference [F],
Δt_2 = Smaller temperature difference [F].

Figure 2 shows that if Δt_1 is not more than twice Δt_2, the arithmetic mean temperature difference will be very close to the true or logarithmic mean temperature difference, but when $\Delta t_1/\Delta t_2 > 2$, the error increases rapidly. To simplify determination of the logarithmic Δt_m the following can be written : $\Delta t'_m = X\,\Delta t_a$, where Δt_a is the arithmetic mean temperature difference, *i.e.*, $\Delta t_a = (\Delta t_1 + \Delta t_2)/2$. Consequently $X = \Delta t'_m/\Delta t_a = [2/\log_e(\Delta t_1/\Delta t_2)]\{[(\Delta t_1/\Delta t_2) - 1]/[(\Delta t_1/\Delta t_2) - 1]\}$, *i.e.* X depends only on the ratio $\Delta t_1/\Delta t_2$.

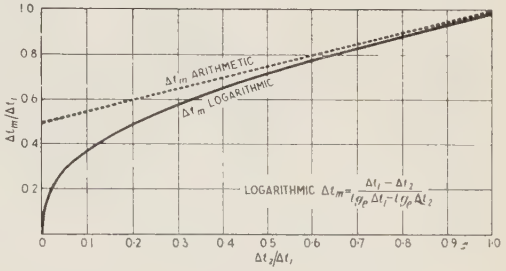

$\Delta t'_m$ ARITHMETIC
$\Delta t'_m$ LOGARITHMIC
LOGARITHMIC $\Delta t_m = \frac{\Delta t_1 - \Delta t_2}{\log_e \Delta t_1 - \log_e \Delta t_2}$
$\Delta t_m/\Delta t_1$
$\Delta t_2/\Delta t_1$

Fig. 2. — Mean temperature difference.

The values of X can be obtained from figure 3. For example, in a radiator into which water enters at a temperature of 210° F. and leaves at 190° F., air enters the radiator at 100° F. and leaves at 150° F. Then $\Delta t_1 = 40°$ F. and $\Delta t_2 = 110°$ F. and $\Delta t_2/\Delta t_1 = 2{\cdot}75$, $\Delta t_a = 75°$ F. From figure 4 X = 0·92 so that $\Delta t'_m = 69°$ F.

The performances of a number of matrices are shown in figures 4 to 7. As seen in

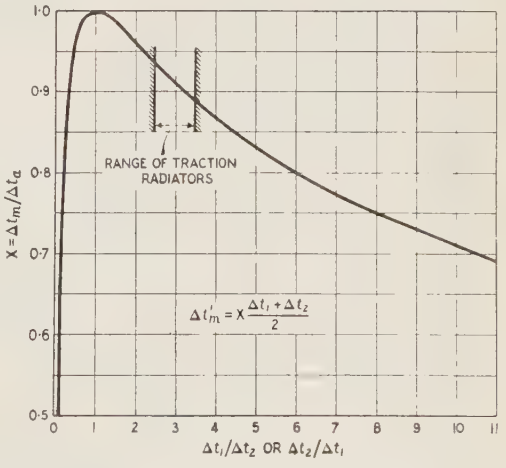


Fig. 3. — Factor X for the determination of logarithmic mean temperature difference.

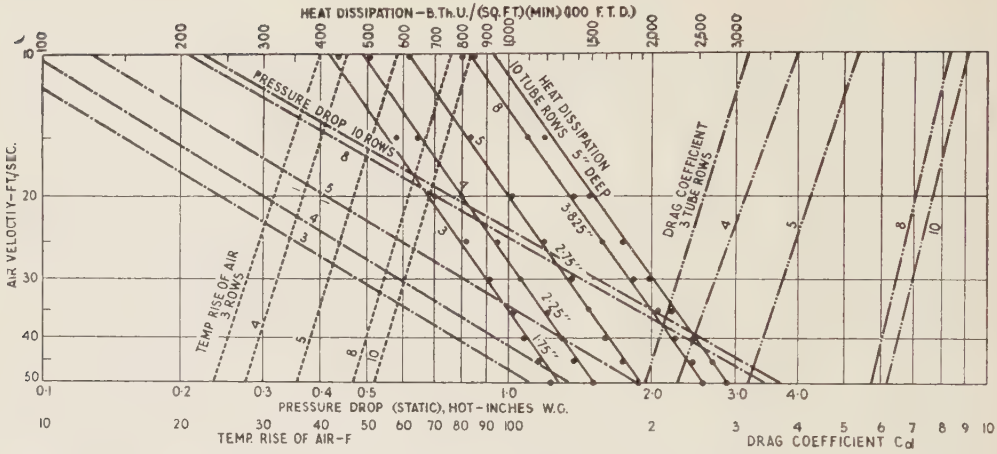


Fig. 4. — Performance of matrices with 8 gills an inch.

figure 4, heat dissipation curves represent average values over the velocity range concerned. Values actually measured deviate slightly, particularly at air velocities below 20 ft./sec. The data have been ascertained for water at 160° F. and air at 60° F., *i.e.*, a temperature difference of 100° F.; this is equal to $\Delta t = [t_3 - t_4)/2] - t_1$ (see fig. 1) and not to $\Delta t'_m$. It will be sufficient to base the determinations on the use of Δt, as, with traction applications, some assumptions must often be made in the design stage, which justifies the use of methods which disregard *minutiae* in determining Q.

The values have been plotted on loga-

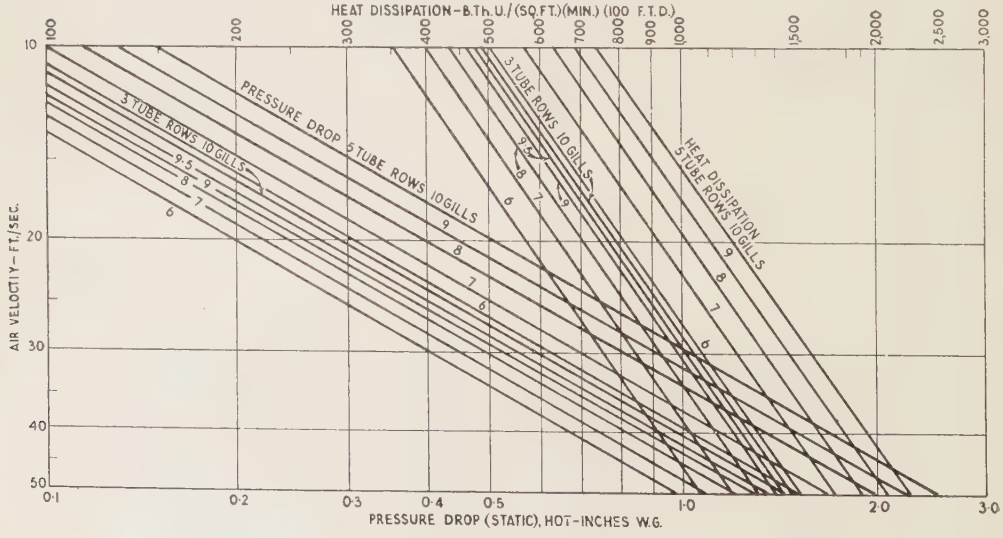

HEAT DISSIPATION—B.Th.U./(SQ.FT.)(MIN.)(100 F.T.D.)
AIR VELOCITY—FT./SEC.
PRESSURE DROP 5 TUBE ROWS 10 GILLS
3 TUBE ROWS 10 GILLS
HEAT DISSIPATION 5 TUBE ROWS 10 GILLS
PRESSURE DROP (STATIC), HOT—INCHES W.G.

Fig. 5. Effect of gills on matrix performance (3 and 5 tube rows).

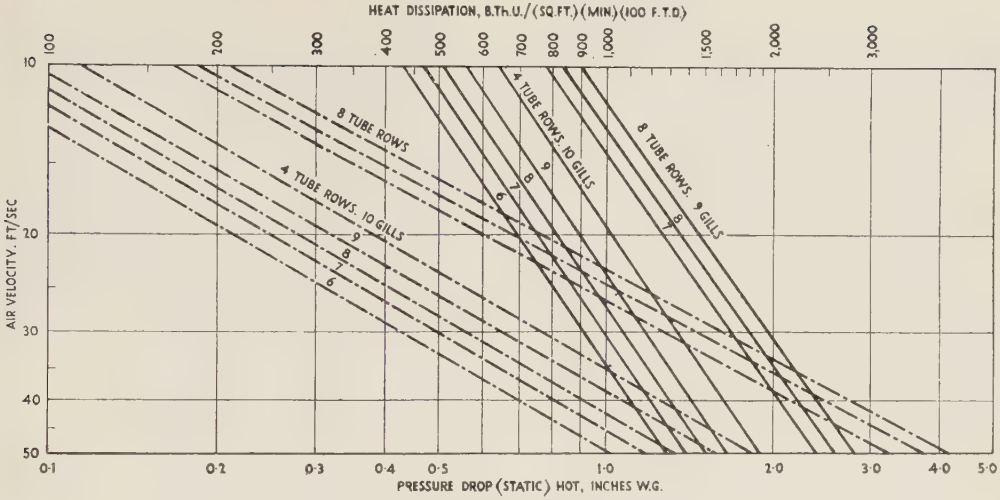

HEAT DISSIPATION, B.Th.U./(SQ.FT.)(MIN)(100 F.T.D)
AIR VELOCITY, FT/SEC
PRESSURE DROP (STATIC) HOT, INCHES W.G.
8 TUBE ROWS
4 TUBE ROWS, 10 GILLS
4 TUBE ROWS, 10 GILLS
8 TUBE ROWS, 9 GILLS

Fig. 6. — Effect of gills on matrix performance (4 and 8 tube rows).

rithmic scales because dependence of the variables on flow velocity thus becomes more apparent. « The linear scale, since it was first cut on the wall of an Egyptian temple, has come to be accepted by man almost as if it were the one unique scale with which nature works and builds, whereas it is nothing of the sort. Its sole value lies in giving due prominence to the differences and sums of quantities, when

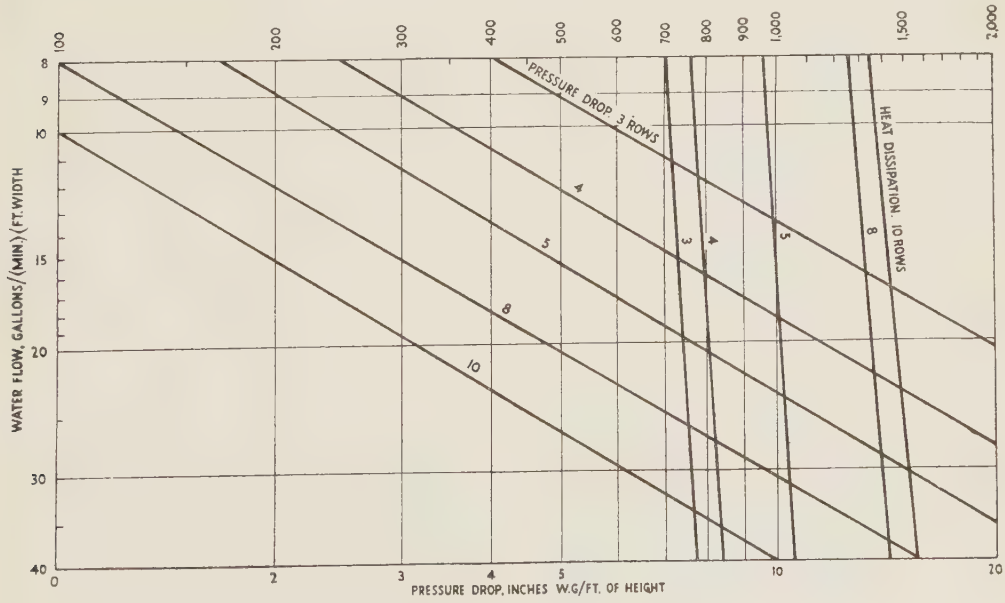


Fig. 7. — Effect of water velocity on performance.

these are what we want to display; but nature, if she has any preference, probably takes more interest in the ratios between quantities and is rarely concerned with the size for the sake of size »[1]

In the writer's experience, eight gills per in. is the optimum in fairly dusty conditions. With less, the matrix performance will suffer (fig. 5 and 6); with more, cleaning may have to be frequent. This amount may be exceeded when operating in reasonably clean air, and also if radiators are accessible for cleaning.

The heat dissipation due to forced convection is given by Nusselt's fundamental expression[2] which states :

$$\frac{h\mathrm{D}}{k} = \mathrm{C}\left(\frac{\mathrm{DV}\rho}{\mu}\right)^{a} \vee \left(\frac{c_p\mu}{k}\right)^{b}$$

where :

h = surface coefficient of convection [B.Th.U./(hr.) (sq. ft.) (F)]

D = diameter of fluid stream in ft. For non-circular sections D = $4r_h$ where r_h = hydraulic radius = cross section/wetted perimeter

k = thermal conductivity B.Th.U./(hr.) (sq. ft.) (F. ft.)

C = A constant

V = air velocity [ft./hr.]

ρ = density [lb./cub. ft.]

μ = absolute viscosity [lb./(hr.) (ft.)]

c_p = specific heat at constant pressure [B.Th.U./lb. F.]

$h\mathrm{D}/k$ = Nusselt number (Nu)

$\mathrm{DV}\rho/\mu$ = Reynolds number (Re)

$c_p\mu/k$ = Prandtl number (Pr)

The values of k and μ depend on temperature; both, within the limits encountered on railways, are practically independent of pressure, whilst ρ depends upon pressure and temperature. The Prandtl number is practically independent of pressure, but curiously enough various authorities differ about its value for air. For example, McAdams[3] gives its value as 0·74 at 212° F. and states that « the effects of temperature and pressure are uncertain, and for the present it is recommended that Pr for gases be taken as independent of temperature and pressure, except near the critical region ». E. Schmidt[4] gives the value of Pr as 0·71 at 0° C. and 0·708 at 100° C., whilst in the English edition[5] of his book Pr is given as 0·696 at 32° F. and 0·695 at 200° F. Brown and Marco[6] give the value of Pr as a function of temperature, though its value is stated to remain constant at 0·77 for air temperatures of 0 to 80° F. Above this, Pr is given as 0·76 up to 800° F. A check of these values shows Pr to oscillate between 0·77 and 0·755 within the temperature range we are mostly concerned here. Max Jacob, in his book mentioned above, gives Pr = 0·74 for all diatomic gases at atmospheric pressure and 212° F. In what follows it will be assumed that Pr = 0·74 = constant. Attention is drawn to these influences here, as the author did not make this as clear as would have been desirable in his article on the effect of air condition on cooling performance in the October, 1949, issue of *Diesel Railway Traction*.

For fluids in pipes generally, C = 0·023, a = 0·8 and b = 0·4. For air, Pr = 0·74 so that generally $\mathrm{Pr}^{0.4} = 0.886$ = constant. Consequently $\mathrm{Nu} = 0.021\ (\mathrm{Re})^{0.8}$. For fluids outside pipes, generally, McAdams[3] gives :

$$\mathrm{Nu} = 0.33\ (\mathrm{Re})^{0.6}\ (\mathrm{Pr})^{0.33} \simeq 0.31\ (\mathrm{Re})^{0.6}$$

This applies to not more than ten tube rows, the air flowing normal to banks of staggered, not baffled, tubes and Re exceeding 2 000. Lander[7] suggests for tube banks :

$$\mathrm{Nu} = 0.29 \times f \times \mathrm{Re}^{0.61}$$

where value of f varies between 0·8 and 0·1 for inline arrangement of tube banks and between 0·98 and 1·14 for staggered tubes (for Re = 8 000). The velocity is at the narrowest point.

Analysis of the data in figures 4 to 6 shows that the heat dissipation is proportional to the 0·7 power of air velocity or,

more correctly, $Re^{0.7}$, *i.e.*, $Nu = C\ (Re)^{0.7}\ (Pr)^{0.33}$. For the radiators dealt with, the value of $C\ (Pr)^{0.33}$ amounts to about 0·062, so that for the air side of the ten row matrix:

$$Nu = 0{\cdot}062\ (Re)^{0.7}$$

The area involved here is the total tube (primary) and gill (secondary) area (both sides). Since the ratio of these areas (with 8 gills per in.) amounts to 1 to 4·45, for the primary area alone :

$$Nu = 0{\cdot}226\ (Re)^{0.7}$$

For the eighth row, eight gills per in. matrix, the corresponding values are :

$$Nu = 0{\cdot}07\ (Re)^{0.7}$$

and

$$Nu = 0{\cdot}33\ (Re)^{0.7}$$

The drag coefficient values plotted in figure 4 have been calculated in accordance with the following approximate equation :

$$C_d = 2\ [T_1/(T_1 + T_2)]/2\ \Delta/p_{st}\rho_1 V_1^2)$$

where :

Δp_{st} = static pressure drop [lb./sq. ft.]

ρ_1 = air density before radiator [lb. sec.^{2}/ft.^{4}]

V_1 = air velocity before radiator [ft./sec.]

T_1 = absolute air temperature before radiator [deg. R.]

T_2 = absolute air temperature after radiator [deg. R.]

The pressure drop data plotted in figures 4 to 6 shows that Δp_{st} is proportional to the 1·75 to 1·8 power of V, or, more correctly, to the 1·75 to 1·8 power of the Reynolds number, *i.e.*, $\Delta p_{st} = \text{Const.} \times (Re)^{1.8}$, whilst C_d is proportional to $(Re)^{-0.2}$. The values shown are the mean over the entire range. Frictional pressure losses with streamline or laminar flow are a direct function of velocity, whilst with turbulent flow the losses are proportional to the square of velocity. As discovered by Blasius in 1913 the magnitude of Re is the deciding factor in determining whether the flow is streamlined or turbulent. For smooth pipes the critical Reynolds number range is about 2 000-4 000. The critical Re is that below which, in a straight long cylindrical tube, disturbances in the flow will damp out. Above the critical Re disturbances never damp out. The critical Re so defined was found by Schiller[8] to be approximately 2 350.

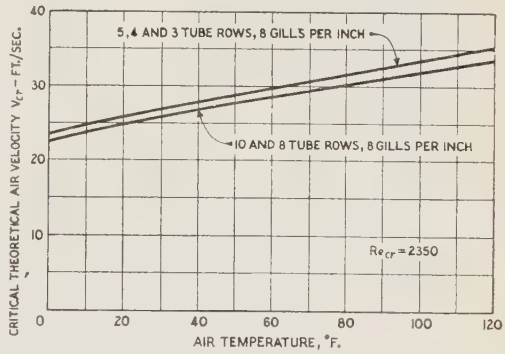


Fig. 8. — Critical air velocity through matrices.

The corresponding critical velocity V_{cr} for air at 0° F. to 120° F. passing through the matrices is plotted in figure 8. The action of the gill ridges and the tubes upon the flow pattern has not been taken into account; it is probable that because of these the critical velocities will be well below those shown. It is seen in figure 8 that, as for the conditions on the air side, the pressure losses encountered by the coolant are proportional to $V^{1.7}$, *i.e.*, $\Delta p_{st} = \text{Const.} \times (Re)^{1.7}$. The critical velocity for water at temperatures ranging from 100° F. to 260° F. is plotted in figure 9 for the tubes concerned. Here again the seam might introduce turbulence at slightly lower velocities.

Water velocity has a relatively small influence upon the rate of heat dissipation, the latter being proportional to the 0·06 power of the former within the range shown.

The thermal efficiency or thermal ratio of a radiator is given by :

$$\eta_t = \frac{t_2 - t_1}{\frac{1}{2}(t_3 + t_4) - t_1}$$

As for the data plotted in figure 4, the maximum temperature difference is 100° F., the rises in temperature of the air in F. and η_t per cent are nearly identical. Generally, a η_t of 65 to 70 per cent. should be aimed at. Inspection of figures 4 to 6 shows that η_t is proportional to $(\mathrm{Re})^{-0.2}$.

The dependence of the power required to force the cooling air through the matrices is shown in figure 10. The deeper the matrix, the lower is the power required to dissipate a given amount of heat, as the power absorbed is proportional to the cube of the air velocity whilst the heat dissipation is proportional to the 1·7 power of velocity. The use of larger radiators will also reduce the power required to drive the fans, but here space is the main consideration. Matrices made up of two or more blocks with suitable gaps between them in the direction of the flow (*i.e.*, discontinuous fins) are uneconomical as regards space, weight and power requirements. In addition, their air passages are liable to clogging by dust, and so on, trapped in the gap, from which its extraction is difficult.

The matrix types considered have a total area to frontal area ratio of 30, 48, 67 and 68 for the 3-, 4-, 5-, and the 8- and 10-row 8 gills per in. matrices respectively. The

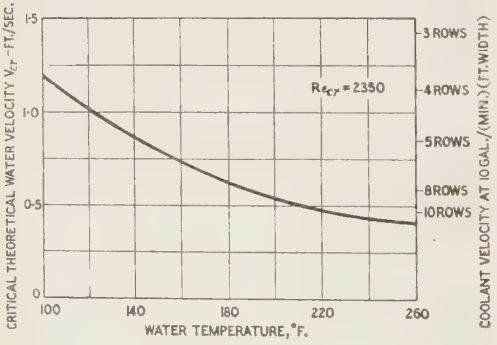


Fig. 9. — Critical water velocity through matrix tubes.

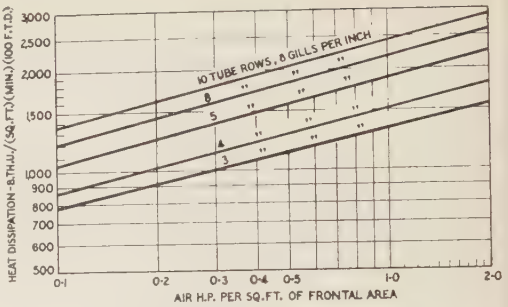


Fig. 10. — Air h.p. as a function of matrix type.

ratio of free area (made available to the air flow) to frontal area is about 0·65, for the 3-, 4- and 5-row, and 0·67 for the 8- and 10-row matrices. The air velocities referred to in the various graphs, however, relate to the frontal area. The matrix weight is 8, 10·3, 12·6, 18 and 22·3 lb. per sq. ft. respectively, when filled with water.

Acknowledgment is made to the Chief Scientist, Ministry of Supply, for permission to publish this article.

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[656 .25 (42)]

Southern Region colour-light signalling.

(From *The Railway Gazette*.)

In 1946 the Southern Railway announced a four-stage scheme, to cost £ 1 750 000, intended to provide continuous colour-light signalling between London and Brighton. Such signalling has existed for several years below Coulsdon except on the old main line *via* Redhill. The area covered by this scheme is shown on the accompanying diagram, from which it will be seen that it involves a complicated network of lines carrying a heavy electric suburban traffic. These were already equipped with power and automatic signalling at, and for a certain distance outside, the termini. The lines not so equipped had mechanical signalling, working in conjunction with Sykes lock-and-block: this gave good service for some 50 years but was found to be in need of replacement. The increase in the train service also necessitated an improvement in track capacity.

The work includes eleven new signal boxes and is being spread over six years; the first of the four stages, from Bricklayers Arms Junction to Norwood Junction North signal box, was brought into use on the night of October 7 and 8, 1950. The second stage, from Battersea Park to Selhurst, is planned to be completed in 1952. The third stage, which covers the rather involved layout of lines at and between Norwood Junction and Gloucester Road Junction, and forms the link between the stage just completed and the second stage, will be brought into use in 1954, and the final stage, between East Croydon and Coulsdon North, in 1955. The whole area covers 98 track-miles, continuously track-circuited.

The first stage.

The new signal boxes are situated at Bricklayers Arms Junction (55 levers), New Cross Gate (71 levers), and Forest Hill (47 levers). Each has an all-electric type power interlocking frame, following the usual practice on the Southern Region lines, and the signal box structures are of the type already seen there with maintenance staff accommodation, relay and apparatus rooms, accumulator rooms, stores, and working accommodation as required. Equipment associated with the main signalling supply system is also housed in them. These boxes have replaced eight mechanical ones containing 279 working levers. The route-mileage covered is seven (28 track-miles) and in addition to the signals controlled from the boxes there are 38 which operate automatically.

There are 96 main and subsidiary signals of colour-light type, fitted with side lights and showing 4, 3, or 2 aspects, as circumstances require. They are of long-range type and have aluminium alloy castings. The lamps are 12 V 25 W double filament, separate transformers being housed in the signal casting to reduce the voltages, which for general distributive purposes is 110. There are also seven multiple-lamp route indicators and 13 junction indicators, mounted on top of their respective signals without additional supports, a new feature. The signal spacing provides for 2 1/2 min. headway for following stopping trains. Shunting signals are of the disc type, solenoid operated and may be floodlit as necessary.

There are 76 electrical point machines, mainly operated from 120 V accumulator batteries at the three new signal boxes, the batteries being float-charged by rectifiers; there are also stand-by rectifiers for direct point operation if necessary. Points up to 500 yd. are directly operated, but beyond that a contactor relay is employed and supply to the machine taken from a local rectifier. Telephones connected to separate circuits are provided at all automatic and most controlled signals, giving train crews direct communication with the signal box concerned.

There are 140 condenser fed A. C. track circuits, single and double rail, incorporating 150 auto and resonated impedance bonds. Track relays are, wherever practicable, housed in the signal box relay rooms, local controller rooms, or the apparatus cases of automatic signals. The installation in general follows standard Southern Region practice using lead-covered multicore cables — mostly 20 to 40 core for signalling circuits and single wire armoured lead-covered paper-insulated cables for signalling power feeders.

The cable route is almost throughout surface concrete troughing, and the Mechanical and Electrical Engineer's 3.3 kW supply cable is carried in it but in a separate channel — sand filled. The troughing units are 3 ft. long and 15 1/4 in. or 20 1/4 in. wide. Underground cable crossings are at

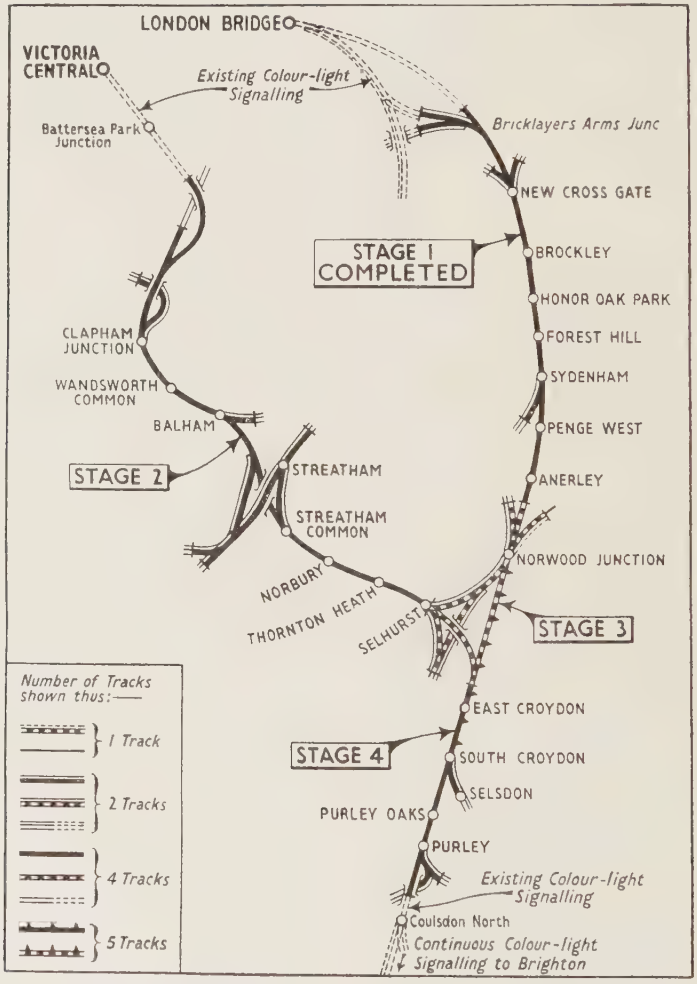

Diagram showing stages of work involved in completing London-Brighton colour-light signalling.

a minimum depth of 3 ft. 6 in. below sleeper level, the cables being in asbestos cement tubes encased in concrete. Large manholes are provided at the approaches to all such crossings. There are nearly 25 miles of concrete troughing carrying 800 core-miles of multi-core signalling cable, 280 pair-miles of telephone cables, dry-core lead sheathed, and single wire armoured, and eight miles of oil-impregnated paper insulated lead sheathed single wire armoured twin feeders from signal boxes to locations.

Behind each point lever is an illuminated « N » or « R » for « normal » or « reverse ».

The illuminated diagrams have the track indications normally dark. That at Forest Hill is of the perspex transmitted light type, described in *The Railway Gazette* for June 30, 1950, p. 736, and has been installed there to enable experience with that design to be obtained.

Magazine train describers enable the signalmen, merely by pressing an appropriate button, to advise adjacent signal boxes of the next train, its class, and

New power signal box, Bricklayers Arms Junction.

Signal box details.

The levers in the power frames have each two lock magnets, one for ordinary interlocking, and the other for track and indication locking. All signal levers are fitted with back or normal indication locks, but front or normal selection locks are not provided. Normal and reverse track locks are fitted to each point lever. Behind each signal lever are repeated all aspects of the signal it controls, red, one or two yellows, or green. Running and shunt signals also have an « F » light indication which, when illuminated, tells the signalman that the signal can be cleared by reversing the lever.

destination, there being an instrument at the « receiving » box with descriptions corresponding to those on the instrument at the « sending » box. The receiving instrument indicates the first, second, and third trains, the indication automatically stepping up one as each first train is cancelled on passing. There are 15 sending and 15 receiving instruments, together with associated equipment. There is also telephone communication with signals, adjacent signal boxes, and « traffic control », the telephone positions being duplicated as necessary so that the booking lad also can deal with calls.

The relay rooms house main transformers, fuses, rectifiers, and all the control apparatus on which depends safe operation. The main signalling supply at each is 480 V from the Mechanical and Electrical Engineer's portion of the signal box. Local distribution is at 110 V, but all automatic signal and other major locations are fed at 480 V. The controlling relays, of which there are 760 in the various rooms, are on steel racks conveniently placed for observation, testing, and changing. The fuse and cable termination panels, also of steel, are about 20 ft. long, and each fuse panel carries 500 to 700 fuses; 110 miles of flameproof wire have been used in the signal boxes and relay rooms.

Pre-cast reinforced concrete signal structure.

Power supply and distribution.

To provide the power for the whole scheme a 3.3 kV 50 c. p. s. three-phase distribution system is being installed. When completed it will form a ring main between Waterloo and Croydon *via* Forest Hill and *via* Streatham. The first section between Waterloo and Croydon *via* Forest Hill has been completed. Whilst initially this has been provided for the signalling it is intended to develop it to distribute supplies for all ancillary purposes along its route. The whole of the power supply equipment comprising the 3.3 kV distribution system is arranged for supervisory control from a central control room at Waterloo. Arrangements are provided to enable the equipment to be operated by remote or local control as required.

Power is taken at Waterloo from the London Electricity Board's 11 kV three-phase, 50 c. p. s. system, and transformed to 3.3. kV for distributions to the signal boxes, where single-phase supplies are taken at 480/240 V. The equipment there comprises an 11 kV switchboard, a 500 kVA. 11/3.3. kV three-phase transformer and a 3.3 kV switchboard. The 11 kV switchboard consists of five metal-clad, horizontal draw-out type oil circuit breakers and one metering panel. Two of these circuit breakers control two incoming feeders from the London Electricity Board; another circuit breaker controls the supply to the transformer, while the remaining two cir-

cuit breakers are for future extensions. The output from the transformer is taken to the 3.3 kV switchboard, which is formed of three metal-clad, truck type, oil circuit breakers for controlling the supply to two outgoing feeders to the ring main. The rupturing capacity of each of the 11 kV oil circuit breakers is 150 M V A. and that of the 3.3 kV circuit breakers is 25 M V A.

A 3.3 kV three-phase stand-by supply is available for feeding the distribution system in an emergency at the traction substation at South Croydon. This is provided by a connection, controlled by an oil minimum type circuit breaker, from the substation's 33 kV bus-bars which are fed through the 33 kV network from the grid. This 33 kV supply is transformed to 3.3 kV through a transformer of 500 kVA capacity. A 3.3 kV oil circuit breaker, together with its auxiliary equipment, is mounted in a kiosk.

The ring main feeder is a three-core 3.3 kV impregnated paper-insulated, lead-covered and armoured cable of 0.2 sq. in. cross-sectional area. With the power cable is laid a 12 core, paper-insulated, lead-covered and armoured composite pilot cable, four of the cores of which are impregnated paper-insulated, laid up together, and screened to form the pilot wires used in connection with a Translay system of feeder protection. The remaining 8 cores are dry paper-insulated, and are arranged in two groups of four, to form the pilot wires used with the supervisory control system. These cables are laid generally in concrete troughing, partitioned to form two channels. One is used solely for housing the power cable, the other for the pilot and signalling cable. The Signal and Telecommunication Engineer's route is used where there are new signalling cables.

In each of the new signal boxes where a 50 c. p. s. single phase supply is taken, accommodation has been set aside, subdivided into three sections, one for the switchgear and auxiliaries, and two for

New signals and junction indicators at Bricklayers Arms.

housing duplicate transformers. The switchgear comprises a 3.3 kV switchboard formed of units of truck mounted, metal-clad, oil circuit breakers. One is provided to control the 3.3 kV supply to each of the transformers, and one or more to control the sectioning of the 3.3 kV system. Two standard sizes of transformers are used, namely, 50 and 30 kVA. The low-voltage connections from these at each of the distribution points are taken to change-over contactor equipment, arranged so that only one transformer is on load at any one time. In the event of failure of this transformer the supply is automatically changed over to the second. Supplies for the operation of switchgear and supervisory remote control equipment are obtained from 60 and 24 secondary cell batteries respectively. At the Waterloo control room special batteries of 50 Ah capacity are installed, but in general D. C. supplies for operating the power supply equipment at the new signal boxes are obtained from batteries installed for operating the signalling equipment. The batteries are charged through metal rectifiers and are normally left on trickle charge.

The whole of this new work has been designed, and the completed stage carried out, by the Signal and Telecommunications Engineer's Department, the number of men engaged varying between 50 and 150, as work progressed. The 3.3 kV distribution system was designed and provided by the Mechanical and Electrical Engineer.

Relay room showing relay racks and fuse panel, Forest Hill signal box.

In the construction of the signal boxes, designed and constructed by the Chief Civil Engineer, Southern Region, to the requirements of the Signal and Telecommunications Department, different foundation problems were met with at each site. At New Cross Gate a reinforced concrete raft was used; at Bricklayers Arms Junction, it was found necessary to put down *in situ* piles about 30 ft. long; whereas at Forest Hill mass concrete piers were built in pits carried down to a gravel stratum.

As regards the superstructures, 13 1/2 in. brick walls throughout have been employed to give adequate insulation against dampness and temperature changes. The floors and roofs are of reinforced concrete with cavity ceilings and asphalt roof covering. Central heating is provided from a boiler below ground level. The resulting structures are clean and satisfactorily dust-proof, well-lit naturally and artificially, providing a good standard of comfort for the staff and fire-resistant to a high degree.

Power locking frame and train describers, New Cross Gate signal box.

The signal supporting structures for this first stage in the work are all of the cantilever type and are required to possess a high standard of rigidity to give a steady colour-light beam. The majority are of pre-cast reinforced concrete, each comprising one large unit of about 4 1/2 tons weight. They were made in the Regional concrete works at Exeter and transported to the site by rail and quickly erected by crane on previously prepared bases of reinforced concrete. The larger cantilevers, exceeding about 16 ft. and increasing up to 30 ft., are of welded steelwork, metal-sprayed for long-term weather protection. These were supplied in two units each and were quickly erected on previously prepared reinforced concrete bases incorporating heavy anchor bolts. All are of clean appearance and calculated to require a minimum of maintenance and appear to possess adequate stiffness under conditions of some difficulty.

The work in general, with small variations in certain details, follows the practice standard for some time on the matter of power signalling for electrified lines adopted elsewhere on this Region, thus maintaining circuit controls and methods of operation by signalmen already well established and found to give satisfaction under the prevailing conditions. While no very complicated layout is involved in this first stage, some of the later work, such as that around Gloucester Road Junction, Croydon, will cover a number of interconnection lines carrying frequent services over a considerable variety of routes.

385. (06 .111]

OFFICIAL INFORMATION

ISSUED BY THE

PERMANENT COMMISSION

OF THE

International Railway Congress Association.

ENLARGED MEETING OF THE PERMANENT COMMISSION (Stockholm, 1952).

LIST OF QUESTIONS

for discussion

WITH THE NAMES OF THE REPORTERS.

1st SECTION : WAY AND WORKS.

QUESTION I.

A. — What are the new safety measures taken for level crossing of railway tracks by the Road in respect of the density, high tonnage and speed of the road traffic?

In particular automatic signalling and closing of level crossings without keepers, worked by the trains themselves.

Technical and statistical investigation in order to ascertain the relative safety of :

1° level crossings with keepers, with the different devices to announce the arrival of the trains to the keepers;

2° level crossings without keepers :

a) without any self-acting device announcing the arrival of trains;

b) with automatic signalling for the road-users;

c) with automatic signalling completed by half- or entire gates.

B. — Level crossing of railway tracks by road with a railway (suburban or urban) running alongside.

Reporters :

English speaking countries :

Mr. Gilbert MATTHEWS, Operating Superintendent, Western Region, British Railways; Paddington Station, London, W 2, and

Mr. S. WILLIAMS, Signal and Telecommunications Engineer, London Midland Region, British Railways; Euston Station, London, N. W. 1.

Other countries :

M. DONIZEAU, Ingénieur en Chef, Chef du Service de la Voie et des Bâtiments, Région de l'Ouest, Société Nationale des Chemins de fer français; 20, rue de Rome, Paris (8e).

3rd SECTION : WORKING.

QUESTION II.

What are the quickest and most economical means to carry out door to door service for railway transports?

What are the best conditions of use of containers for small miscellaneous traffic (dimensions of the containers, conditions of ownership, tariffs)?

What are the packing types to be recommended?

Reporters :

English speaking countries :

M. M. G. de BRUIN, Directeur général de la S. A. Van Gend & Loos; Moreelsepark, Utrecht.

Other countries :

M. F. SAUVAGEAT, Adjoint au Chef Principal de l'Exploitation des Chemins de fer Fédéraux Suisses; Länggasstrasse, 16, Berne.

4th SECTION : GENERAL.

QUESTION III.

Economic aspects of :

a) discontinuing service on old railway lines;

b) construction of new railway lines;
with regard to the possibility of handling transport with other means.

Reporters :

English speaking countries :

Mr. Arne SJÖBERG, Chief Research Economist, Swedish State Railways; Stockholm.

Other countries :

M. MOULART, Ingénieur en Chef à la Direction de l'Exploitation de la Société Nationale des Chemins de fer belges; 17, rue de Louvain, Bruxelles.

NEW BOOKS AND PUBLICATIONS.

[385. (02]

The Directory of Railway Officials and Year Book 1951-1952. — One volume (8 1/2 × 5 1/2 in.) of 626 pages. — London : *Tothill Press Limited*, 33, Tothill Street, Westminster, S. W. 1. (Price : 40 s. net.)

The Directory of Railway Officials and Year Book 1951-1952 reaches with the present volume its 57th year of publication.

The first edition was compiled from official sources and issued in 1895, and at that time some 270 pages sufficed to cover the text including an index to countries, an index to names of railways and the comprehensive personal index of railway officials, which is still a noteworthy feature of the volume.

The present edition should prove at least as valuable as its predecessors in containing within the scope of little more than 600 carefully-condensed pages more comprehensive lists of officers and particulars of railways throughout the world than can be obtained from any other publication in any language.

The information contained in this volume enables railway officers and others to keep in touch with the personnel on railways throughout the world for the exchange of information concerning research and developments in all phases of railway operation and maintenance.

Official revision of entries has been made in the present volume for a number of countries from which details have not been received for many years. These include Japan and the U. S. S. R., and various (although not all) countries of Eastern Europe. A new entry is that for Saudi-Arabia, and particulars relating to Austria have been expanded.

The order of the statistical and year book information has been rearranged to secure a more logical sequence. Sections which are entirely of historical interest have been omitted. Additions of great interest have been made (new loading diagram for British main-line passenger rolling stock, details of right and left hand running through the world, review of train accidents in Great Britain in 1949, etc.).

All entries are divided into one of two main divisions, namely, British Commonwealth (regardless of dominion or colonial status) and Foreign. Each of these sections is again subdivided geographically into Continents as follows :

Europe, Australia and New Zealand,
Asia, North America,
Africa, South and Central America.

For ready reference purposes at the end of the volume will be found three indexes :

1) an index to countries;

2) a general index including all references to railways and statistical and other information;

3) a personal index of railway officials.

[385 .06 .1 (7 + 8)]

VI Congreso Panamericano de Ferrocarriles (*Report of the sixth Panamerican Railway Congress*). Havana, March-April 1948. — 6 volumes (7 · 9 7 8 inches) totalizing 3 500 pages approx., illustrated. — 1949, Habana, Imp. y Alm. de Papel « La Habanera », M. Mercaderes, N° 208.

With Buenos Aires as its headquarters, the Panamerican Railway Congress held its previous meetings at Montevideo. These took place in the capital of the Queen of the West Indies. The official ceremonies which preceeded and succeeded the meetings devoted to work were no less solemn than those in the capital of Uruguay. Many public meetings showed the interest taken by the Public Authorities in such a concourse of railway specialists. Two decrees of the President of the Republic laid down the composition of the Organization Commission in the one, and the composition of the Cuban Delegation to the Congress in the other.

This Congress is truly panamerican owing to the participation of all the South American Republics and various States of North America, for example Mexico and the United States. The great American Railway Association sent a large number of communications.

In some ways, the organization is similar to that of our own sessions. It differs by the greater liberty left to the initiative of members in presenting reports, so long as those are connected with subjects mentioned in the programme drawn up by the Permanent Commission. There were 18 such subjects, divided into six groups corresponding to the six working sections of the Congress. These six sections are defined as follows : Way and Works, Rolling stock and Traction, Working, Accounts and Statistics, Legislation and Administration, and General Matters.

So long as they are connected with the subjects given, the communications presented to the Congress can be simple reports of applications made or results obtained or studies developing a thesis and putting forward new suggestions.

The reports are not published beforehand. After discussion by the sections, the suggestions are examined during plenary meetings at which it is decided whether they shall be published. Generally, it is decided that they shall be. It is these reports, together with the discussions by the sections and the suggestions adopted by the sections and at the plenary meeting that make up Volumes II to VI.

Volume I contains the official documents: the organization decrees, the composition of the organization committee, the programme drawn up by the Permanent Commission, the regulations of the Congress, the list of works presented and the names of the reporters, the list of delegates, the Congress Authorities and the Sections and the agenda of the Congress. Finally, it gives the complete programme for the preparatory meeting, the solemn opening and closing meetings, together with a very complete report by the President of the Permanent Commission dealing with the position of the Association. The reporters are not the authors of the works presented, but those responsible for commenting upon them to the Sections.

Full credit must be given to the editors for the original and animated character given to this document by the photographs included and the press reports, which are full of picturesque details. There are even caricatures to enliven things.

The Congress had 118 communications to examine. In general, these were inspired by the preoccupation to make the construction and maintenance of the permanent way, the rolling stock and the operating methods profit from the technical progress being made. In the matter of accountancy, the analysis of the costs has been extended

in order to determine the cost of the various methods of transport. Legislation is re-examined at the same time as the nationalization of the railways, and with the object of making the rates more flexible. Amongst the general questions, no one will be astonished to see the question of competition cropping up once more, together with the ways of improving the railway services, and finally the problem of co-ordination. Very deep studies were presented on these two latter subjects by delegates from various member countries.

These reports of the Havana Meeting are a proof of the growing vitality of the Panamerican Congress and bring out very clearly the importance of the part played by the railway on the other side of Atlantic.

E. M.

[**621** .13 (02)]

SELLS (M. P.), O. B. E., M. T. Mech. E., M. I. Loco. E. — **The Steam Locomotive of to-day.** — One volume (5 1/4 × 8 1/4 inches) of 250 pages with 160 figures and plates. — 1951, London, The Locomotive Publishing Co. Ltd., 88, Horseferry Road, Westminster, S. W. 1.

This book was written for the benefit of the steam locomotive crews and maintenance staff. It is based on the constant preoccupation to retain the highest possible degree of regularity, a striking quality which other methods of transport may well envy the railway.

To achieve this object, it is not sufficient merely to have available well designed and well built stock, but a well trained and educated staff is also needed. From this latter point of view, such a book as this can be of great value.

In the first group of chapters, the production of steam is studied under its various aspects : fuel and combustion, steam as a fluid transporter of heat, the boiler and its accessories. Superheated steam and superheaters are the subject of a special chapter.

Details on the transformation of heat into work, the calculation of the tractive effort and powers lead the way to a study of the distribution system. Various very educational diagrams support the explanations of the cycle followed by the steam in the cylinder and the working of the Walschaert valve gear. Drawings also explain the descriptions of the servo-motor reversing gear.

In the chapter on braking, the author describes the vaccum and compressed air equipment, with numerous diagrammatic drawings intended to make it easy to understand the correct way of operating them.

In the case of lubrication, it is essential to understand the characteristics of the various materials used. The staff will find them briefly described, together with the methods to which they lend themselves. Their curiosity should be completely satisfied by the explanations given of the hydrostatic and mechanical lubricators.

The next two chapters give a lot of information about the construction of the frame and mechanism. A knowledge of these constructional details will greatly facilitate the work of the engine crews. It is necessary to enable them to understand the measures to be taken in case of damage, such measures being described in a further chapter.

A summary of the duties of firemen and drivers is given in two separate chapters. The wise advice given to the former about the management of the fire and the recommendations to the latter regarding the operation of the brakes under various circumstances will be noted.

This second edition has been increased

by a new chapter on shop practice. The tolerances for adjustments, the limits of wear, the composition of ferrous and non-ferrous metals are amongst the details the great value of which will be readily appreciated. We must also mention the details regarding the maintenance of the superheaters and the notes on certain applications of electric welding.

« The Way of Efficiency » is the title of the last chapter in which are collected together certain important advices, the observation of which will largely increase economy and regularity.

In an appendix the author gives the English and American methods of representing the wheel arrangement by numbers and gives a description of the Berkley mechanical stoker.

E. M.

[**385** (05 (460)]

Annuario de los Ferrocarriles y de sus Transportes Complementarios 1946-1949 *(Annual of the Railways and their Supplementary Transports).* — Published by the Railway Polytechnical Institute, under the direction of Alfonso Imedio Diaz, Doctor of Law, Divisional Assistant Manager, Head of the Passenger Traffic Department of the Spanish National Railways. — One volume (6 1/4 × 8 1/4 inches) of 462 pages. — Madrid, Instituto Politecnico de Ferrocarriles, Plaza de las Cortes, 3, primero.

This book contains the official addresses of all the authorities having anything whatsoever to do with railway operation.

First of all, there are the officials and organizations belonging to or attached to the Ministries. The most important in this connection is the Ministry of Public Works which includes amongst its attributes the control of the railways and consequently the General Management of the Railways, Tramways and Road Transport Services.

Then there are the railways : the R. E. N. F. E. (Red National de los Ferrocarriles Espanoles) i.e. the Spanish National Railways, the narrow gauge State Railways and private Railways, the Metropolitan lines and the Tramways.

Many international organizations, undertakings and institutions connected with the railways, the chambers of commerce and national and foreign industry, the transport offices are also included, with details of their head office and directors.

Brief statistics are given to show the importance of the various undertakings.

At the end of the book, there is a bibliography listing the chief periodicals and recent books dealing with transport questions.

This annual will obviously be very useful in Spain, especially since the reorganisation of the R. E. N. F. E. Abroad it will be appreciated for the numerous commercial and administrative details it contains.

E. M.

[**656**]

Dr. Eng. PIRATH (C.), professor at the Technical High School of Stuttgart. — **Die Grundlagen der Verkehrswirtschaft.** *(The Foundations of the Economics of Transport).* — Second Edition. — One volume (6 3/4 × 10 1/4 inches) of 316 pages, illustrated, 2 plates. — 1949, Berlin W. 35, Springer-Verlag, Reichpietschufer, 20. (Price : 39 D. M.).

One of the striking phenomena of the economic life of our times is certainly the extraordinary development of methods of transport. This is seen not only in the extension given to the existing methods of transport and the various improvements

from which they have been able to benefit thanks to technical progress, but also in the creation of new methods of transport.

There is no doubt that the increasing number and variety of methods of communication meet the new and increasing demands. Industry, commerce, and social and cultural life, in perpetual evolution, daily require faster, or more frequent, or more convenient services.

Does this mean that all the services offered to the public have always been conceived on rational lines ? Are the legislative and administrative measures intended to confirm the various undertakings in the role which naturally falls to them ? These are questions whose solution involves lengthy studies and which vary from country to country.

The definition of a rational transport policy and deciding the decisions to be taken in various cases necessitates preliminary initiation and the constitution of a special documentation. From these two points of view, this book will be of great assistance to those with initiative or responsibilities to undertake in connection with transport matters.

Doctrinal in character, it studies transport in general. It defines its economics and signification in the general organization of a country. It analyses the factors setting it in motion and the different forms in which it can be realised.

A methodical study of the traffic, its distribution and its variations in locality and time leads to the examination of its relationship with the economic life of the country.

Each method of transport has its own characteristics. The safety, the regularity of the service, the possibilities, the limitations, are all factors to be taken into account when it is question of choosing between several possible solutions or making extensions. In spite of their importance, they are still subordinated to their efficiency and usefulness for the community.

In these few lines, we have not tried to sum up the book, but merely to explain some of its leading ideas. Amongst these we must also mention the rational management of the undertakings and principles of organisation.

As regards this always controversial question, we can read with interest the history of the relations between State and transport. In the same way the discussion of the circumstances in which competition develops and the advantages and possible dangers of unity of transport is a very topical matter. If we want to know the personal opinions of the author, we can appreciate them in the light of the arguments put forward.

There is a copious bibliography at the end of the book and an alphabetical list of the subjects dealt with.

E. M.

[385 .1 (4)]

The situation of the European Railways. Difficulties, causes, possible remedies. — One brochure (8 1/4 × 10 5/8 inches) of 38 pages. — Published by the International Railway Union (February 1951).

Much has already been written on the financial and material situation of the railways, on competition and the organization of transport. Very detailed studies have appeared in this *Bulletin* in the form of reports drawn up for Sessions of the Congress where they gave rise to extremely interesting discussions. Yet, these efforts do not seem to have met with their due reward up to the present. The situation has not improved in any way, to the great detriment of public finances and the general interest.

This note is a further report on the situation. It is also an appeal to the Public Authorities. It has the great merit

of being presented in a concise form and therefore is easy to refer to. The picture is lightly sketched in and the essential facts brought out, showing how they should be improved and what steps should be taken.

The author first of all deals with the thesis according to which the railway is an outdated method of transport no longer deserving of much attention. To those who understand the railway and the services it renders this may seem superfluous. But in our opinion, it would be a mistake to consider as negligible a propaganda intended to weaken the moral credit of the railway. Certain sections of the press, who do not wish to find any other remedy than a reduction in the costs, tend to spread the belief that this will make everything perfect. The argument can be taken very far. Was there not recently a call for the « derailwayisation » of Europe? It is very good to have some counter-propaganda showing the inanity of such ideas and making known the role and importance of the railway.

To characterise the present situation, the author analyses the burdens and obligations which continue to weigh upon the railway whereas the monopoly which justified them has disappeared. He shows how this has led to a situation which everyone will agree is deplorable.

Whilst crying out against the wrongs of this regime, the managements of the railways have done everything possible, in spite of the chains which impeded them, to limit or correct the effects of this state of disequilibrium. Yet the improvements made in the operating and in all the supplementary services are still inadequate. The note demonstrates the need for a radical modernisation of the railway which could be done if the Public Authorities would support the programme outlined without reservation. In what direction should the Public Authorities act? This is what the note indicates in this chapter and makes clear in the succeeding chapter by detailing the remedies on the national scale. This will also require as their essential complement remedies on the international scale, as it is not possible to leave the field free for inordinate competition if the effects of these reforms are not to be spoilt.

In the chapter devoted to general conclusions the author gives a view of the steps proposed as a whole and restates the dilemma. Either the railways, which are a necessary part of the life of the country, must be left to live normally and march forward as progress is made, or else we must be resigned to seeing their finances remain in this mess and impede every effort they make to fulfil with dignity their role of public service.

It is to be hoped that this study will be widely read. With well-found arguments, based on the general interest and issued by an organisation which includes undisputed authorities, it should have the privilege of attracting the attention of the responsible Authorities to the true aspects of the railway problem.

E. M.

[**625** .14 (02]

LAMALLE (U.), Civil Engineer of Mining A. I. Lg., Honorary General Manager of the Belgian National Railways. — Professor of the University of Louvain. — **Cours d'exploitation des Chemins de fer,** *Tome III :* **La Voie.** — *(Railway Operating Course. Volume III : The Permanent Way).* 2nd edition. One volume (7 7/8 × 10 1/4 inches) of 256 pages and 346 figures. — 1951, Louvain, Librairie Universitaire Ch. Uystpruyst, 10, rue de la Monnaie, and Paris, Dunod, 92, rue Bonaparte, éditeur. (Price : 300 Belgian francs.)

Some ten years have elapsed since the publication of the first edition of this work by M. Lamalle. During these ten years technique has made yet further progress, just as ideas also have suffered an evolution, in spite of and partly because of the violent events which have shaken the whole world.

The need to reconstruct many miles of line has led to certain problems in connection with the superstructure being looked at in a different way. On the other hand, metallurgy has made further progress and the economic crises, the effects of which are still being felt, have modified the conditions under which materials are purchased. Railway operators have endeavoured to an ever increasing extent to reduce the capital cost whilst not overlooking subsequent maintenance costs.

Though it does not differ much from the first edition, this second edition bears the stamp of the most recent constructions and reflects the new ideas on the best methods available. In the May 1946 *Bulletin*, a few details concerning the general programme of the work and its main developments were given. There is no point in going into the matter again, but we would like to insist on the didactic character of the work as well as upon its great interest for professionals owing to the positive data and actual results which are given in support of the study.

Addressing himself to engineers and future engineers, the author gives many examples of the influence of economics on the choice of solutions made possible by technical knowledge. In the case of new ideas, he defines the objectives the inventors had in mind, as well as the pitfalls to be avoided and the points which experience has not yet proved.

In the constitution of the superstructure, the disfavour into which the bull-headed rail has fallen must be attributed to economic considerations. The same applies to the use of longer rails and a more thorough study of the rail joint. As regards sleepers, although interesting researches and trials have been made in connection with the use of ordinary concrete and prestressed concrete sleepers, certain reservations must still be made in view of the question of the fastenings and the cost of manufacture.

Without detailing all the matters covered by this work, which is a complete study of the permanent way, we would like to make special mention of the very thorough study from the geometrical point of view of track equipment with details of a method for laying turnouts on curves. Apart from the fear that we might appear to be neglecting other equally important chapters, we would also like to draw attention to that dealing with the working of points and all the electrical and mechanical safety devices. Electric control of points in the case of urban tramway systems is one of the measures applied to facilitate the service and make its working more economical.

To end, we would like to say that it is indeed fortunate that the success of this work has made it possible to publish this new and up to date edition which we recommend all those who have to deal with the construction and maintenance of the permanent way to read and study.

E. M.

[**625** .1 (42) & **656** .222 (42)]

DOW (Georges), M. Inst. T., A. I. Loco. E. — **The East Coast Route.** — One volume (5 1/2 × 8 1/2 inches) of 64 pages, illustrated. — 1951, London, The Locomotive Publishing Company Ltd., 88, Horseferry Road, Westminster, S. W. 1.

East Coast Route ! These three words evoke many memories in English hearts. The East Coast Route is the route linking up England and Scotland and is the field of many remarkable struggles where many records were established.

The traveller, in the *Flying Scotsman*, who during the summer of 1936, covered the 393 3/4 miles between the two capitals non-stop, was not always conscious of the efforts that had been made over so many years to make such a performance possible.

To measure this achievement, it is necessary to follow the author back to the year 1840 and trace step by step the formation and welding together of the many links that

finally completed the chain. One of the difficulties was the existence of the many different companies. Trains were only able to travel from London to Edinburgh by the present route without any retracing of their journey after 1906. Nor is the history of the thrust towards the north, as far as Aberdeen, any less striking. There are two famous bridges on this last part of the East Coast Route, often called the Route of the Great Bridges, but not only on account of these latter : there is the celebrated bridge over the Firth of Forth and that over the Tay.

Kings Cross (London) to Doncaster, Doncaster to Berwick and Berwick to Glasgow and Aberdeen are the three divisions of the East Coast Route over which the author invites his readers to follow him. In passing, he shows them the stations, the bridges, picturesque sites, the business and industrial centres, the railway junctions, the natural obstacles that the railway had to overcome. Great technical achievements like the signalling and up-to-date shops are not overlooked. The incidents related, the anecdotes and dramas recited, throw into relief the work of genius, the audacious solution. A stop at York makes possible a tribute to the two venerable ancestors of our present day locomotives which are amongst the many objects on view at the famous Railway Museum.

The most divers stock has run over these rails which now form a continuous route, from the Single Drivers in the case of the locomotives to the powerful streamlined Pacifics designed to haul the Silver Jubilee. The author calls to mind the most characteristic types. In the same way, he gives the noteworthy stages of the evolution of the passenger stock.

In a final chapter entitled : Some famous express trains of the East Coast Route the reader sees the rise of the famous stars, which illuminate the firmament of the East Coast Route. There is also a description of the struggle between the East and West Coast routes. After various fortunes of war, this ended in the victory of the L. N. E. R. with the performance of the Flying Scotsman described above.

Amongst the other famous trains celebrated in this chapter, special mention must be made of the Silver Jubilee, the first streamlined English express train which from the autumn of 1933 linked up Kings Cross and Newcastle. This was noteworthy both on account of the speeds reached during the preliminary trials, an average of 100 miles over a distance of 43 miles and two peaks of 112.5 miles, and by the world speed record established on the run from Kings Cross to Darlington : timed at an average speed of more than 70 miles an hour over a distance of 200 miles.

The illustrations to this book, copious and varied as they are, are worthy of the great facts related.

The author must also be applauded for the care he has taken to associate in his homage to the work the names of the famous men who shared in it.

E. M.

[**621** .13 (73)]

WOLFF (Adolph, Dipl. Ing.), **Dampflokomotiven der New York Centralbahn für hohe Geschwindigkeit.** *(The New York Central high speed steam locomotives).* — One volume (6 × 8 1/4 inches) of 92 pages, with 62 figures and 2 folding plates. — 1951, Berlin W. 30, Georg Siemens Verlagsbuchhandlung Nollendorfstrasse, 28. (Price : 8.50 D. M.).

There has been a profound and very rapid evolution of the locomotive in the United States of America within a few years. A new traction engine, the Diesel-electric locomotive, has gained the favour of many operators. It made a successful appearance in 1934 on the passenger train services of the Chicago, Burlington and

Quincy Railroad. Since then it has progressed very rapidly. After having ousted the steam locomotive for hauling the best known express trains, it began to be used for the goods services as well.

Today the steam locomotive is still in the majority in the stocks of the American railways, but it is rapidly losing ground, its new competitor being preferred when new orders are placed.

This infatuation is not general however and the steam locomotive has its defenders. The author has not wished to join in the debate which has arisen on the subject, the decision must be left to the Companies. Amongst those who have taken up a radical position is the New York Central whose orders for 1948 and programmes for 1949 and 1950 did not include a single steam locomotive. This decision is all the more remarkable as it was made by a railway which has been noted for a long time in the rational development of locomotives based on scientific research.

Before coming to this turning point in the history of its rolling stock, the New York Central had designed as its latest types with wheel arrangements 2C2, 2D1 and 2D2 some very remarkable engines both as regards their power and their very low specific weight. It is the emotion caused in professional circles which has led the author to take this opportunity of making a retrospective study of the development of the high speed steam locomotive on the New York Central.

The study covers the period between the introduction of the Pacific in 1904 on what was then the Michigan Central to the creation of the 2D2 Niagara type which dates from 1945-46. So as not to make his book too long, the author has not given a detailed description of all the locomotives at the various stages of evolution; he has merely indicated the principal arrangements by means of diagrams, drawings and numerical tables.

Only the 2D2 Niagara type is described in detail with a drawing of the complete locomotive and numerous sections. At the same time the author gives some very interesting details about American practice and about new arrangements, such as the monoblock frame, roller bearing wheels, and the valve gear. As regards the latter, the progressive extension of the Baker-Piliod mechanism will be noted. The interest aroused by it has led the author to give a cinematographic study of it.

Particular attention has been paid to the general lightening of the locomotive. At the same time, to decrease the wear on the rails, the method of introducing counterweights to balance the mechanism has been revised, and the method known as « cross balancing » which the author calls « dynamic balancing » has been adopted. This like the European practice consists of balancing each part by two counterweights calculated according to the position of the planes of action.

The rest of the work deals with the power of the locomotives, their behaviour in service, a study of the steam and draught, and a few particularities of the construction and accessory apparatus.

As regards ease of driving and the realisation of the maximum economy, the author explains the principles and describes the so-called « Pilot Valve ». This enables the driver to use the notch giving the greatest power for each speed.

E. M.

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Dr. Ing. BÄSELER. — Welche Vorteile kann das **durchgehend geschweisste Gleis** bieten? (1 700 Wörter.)

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KLÜSCHE (W.). — Wiederaufbau und Stand der elektrischen **Zugförderung** in Deutschland. (5 000 Wörter, Tabelle & Abb.)

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WAIS (F.). — En el **centenario del Madrid a Aranjuez.** (8 000 palabras & fig.)
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RINALDI (G.). — Prove sperimentali su modello di **trave continua a due campate eguali per ponte in cemento armato precompresso** di grande luce. (3 500 parole, tabelle & fig.)

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LEVI (F.). — Ritaratura degli sforzi nei cavi di un **ponte precompresso** a quattro mesi dalla messa in tensione. (6 000 parole.)

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JANNATTONI (L.). — Nascita e morte della vecchia « **Termini** ». (3 000 parole & fig.)

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SAVERIO MERLINO (F.). — Contributo al **calcolo del ponte Nielsen.** (700 parole & fig.)

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MALINGS (H. V. G.). — Reflections on the 195 **Permanent Way Institution Summer Convention** in Hol land. (2 000 woorden.)

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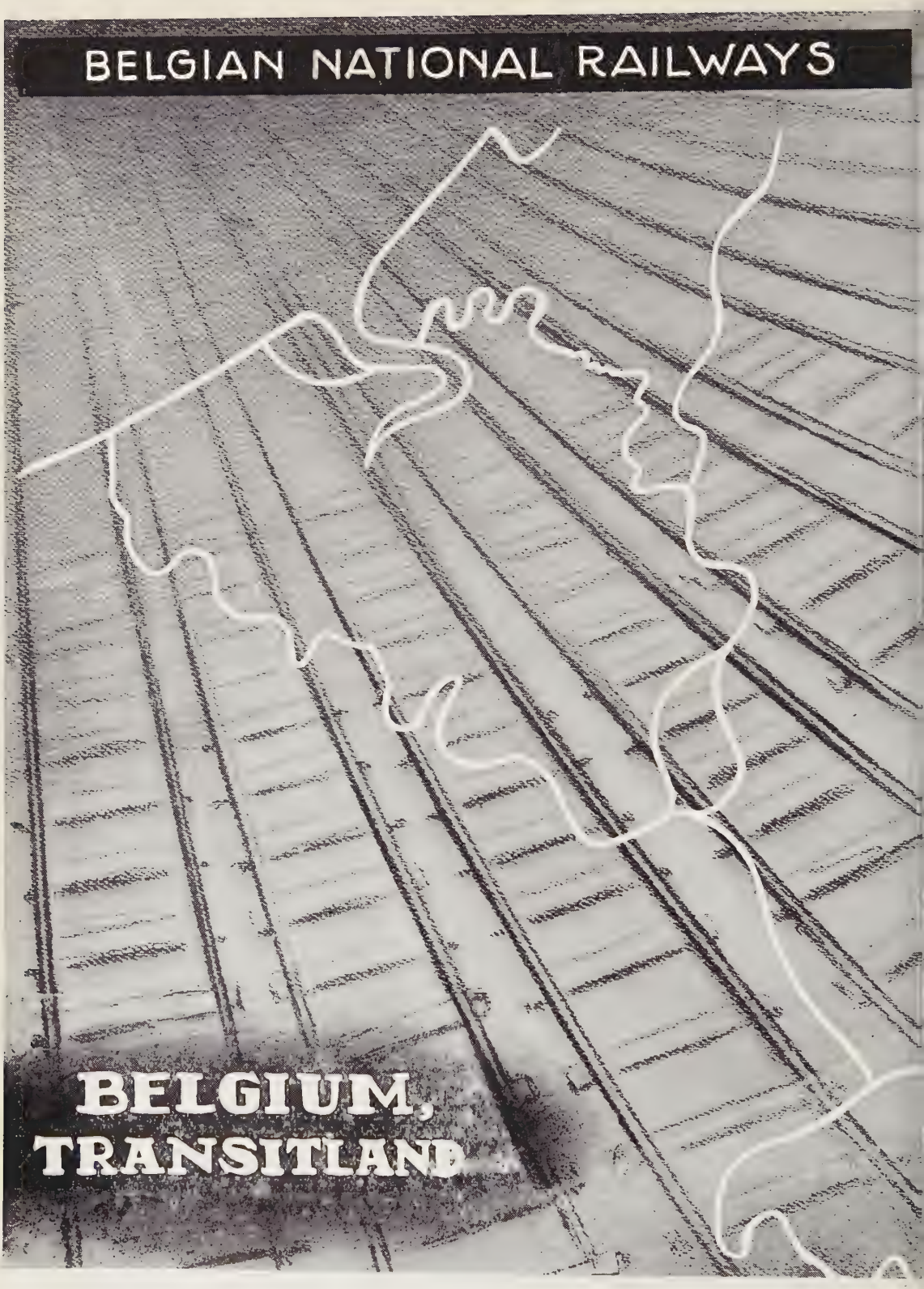
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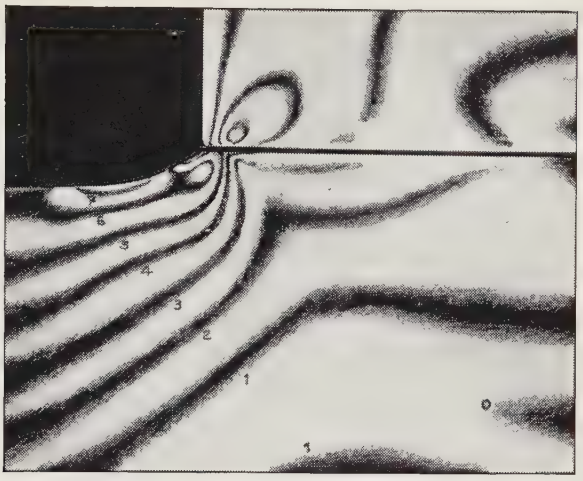

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In every kind of journal bearing, whether plain, ball or roller, there is one dimension that is of critical importance in the performance of the bearing as a load-carrying anti-friction device, and in its durability, and that is the radial clearance.

A badly fitted plain bearing either cannot be turned or soon cries out for help. With an anti-friction bearing, over-tightening could pass unnoticed for a time, until self-destruction of the bearing began to be evident or the axle failed.

In order to make it impossible to over-tighten our bearings, we at Timken have for many years employed a simple system which is as safe as anything can be against the idiosyncrasies of the human element.

The inner element of the bearing is mounted upon the axle shaft by an interference fit, and only two dimensions are involved : one is the bore of the bearing, which we produce to close limits, and the other is the diameter of the axle shaft where it fits into the bearing. This diameter is easily checked by the railway engineers during manufacture, and after that the bearing can be fitted in a simple press, without risk of over-tightening the bearing elements.

The housing for the bearings is so made that the cups and rollers can be inspected without withdrawing the bearing from the shaft.

This system of bearing mounting, approved by French railway engineers, is supplemented by Timken recommendations in respect of stress relief, the two factors together constituting the finest safeguards against axle breakage.

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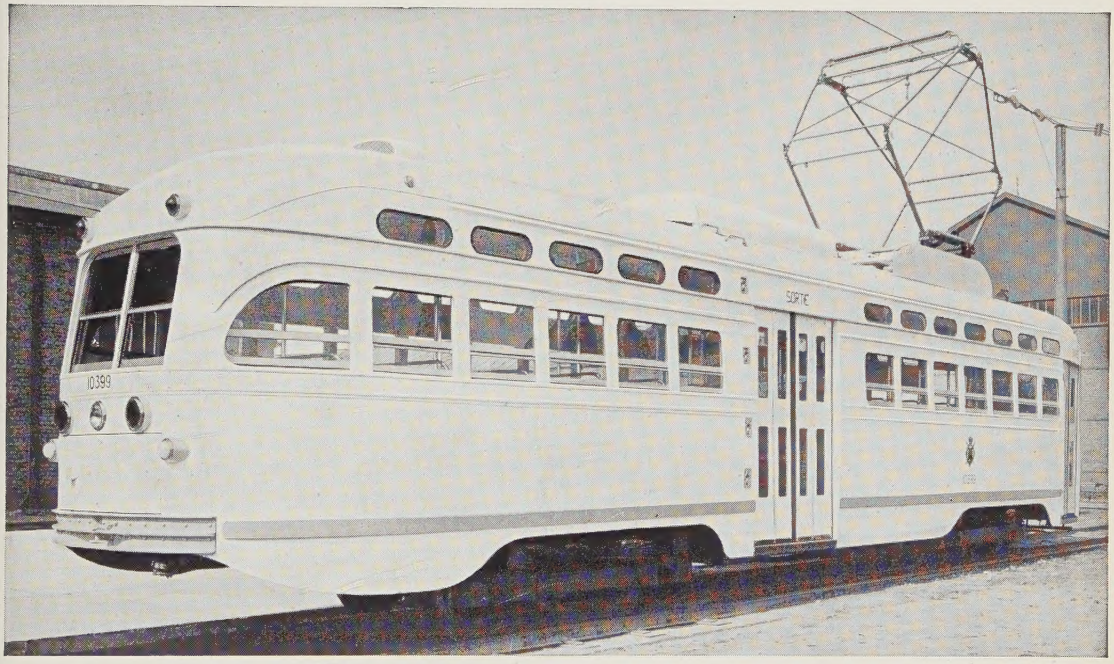

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